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COCKPIT DISPLAYED TRAFFIC INFORMATION STUDY

Boeing Commercial Airplane Co.

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16. Abstract <p>This report presents the results of the Cockpit Displayed Traffic Information (CDTI) study. The purpose of this study was to provide the planning base for conducting a flight test evaluation of an Electronic Horizontal Situation Indicator (EHSI) incorporating the position of other air traffic as derived from ground sensors. <i>study objectives</i></p> <p>The objectives of this study were to: (1) define and scope a system concept for an airborne information display utilizing ground derived ATC and ATC related information (this concept to be based on measurable potential ATC system benefits that are amenable to experimental verification via simulation and flight tests); and (2) prepare an outline of a simulation and flight test program which includes the NASA 515 aircraft, the Langley Research Center traffic simulation and other aircraft and simulations. Testing in a busy terminal area was also to be planned.</p> <p>The general approach was to review the extensive work of other investigators on the CDTI and related concepts, formulate operational concepts for how various roles could be used in the Upgraded Third Generation ATC system (and in realistic terminal area traffic situations), and identify the simulation and testing necessary to evaluate the performance achievable with CDTI.</p>			
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TABLE OF CONTENTS

	PAGE
1.0 INTRODUCTION AND SUMMARY	1
1.1 Introduction	2
1.2 Summary	3
1.2.1 Operational Concepts	3
1.2.2 System Concept	10
1.2.3 Benefits	10
1.2.4 Recommended Test Scope and Objectives	16
1.2.5 Conclusions	16
1.2.6 Recommendations	17
2.0 ATC ENVIRONMENT	19
3.0 ROLE IDENTIFICATION	23
3.1 Candidate Roles	23
3.2 Selected Roles	27
4.0 INDIVIDUAL ROLE CDTI CONCEPTS	29
4.1 Traffic Monitor Roles	29
4.1.1 General TMA Operations	29
4.1.2 Longitudinal Separation of Arrivals	44
4.1.3 Independent Parallel Approaches	51
4.1.4 Runway Occupancy Monitor	68
4.2 Air Traffic Control Roles	79
4.2.1 Arrival Merging	79
4.2.2 Arrival In-Trail Spacing Control	94

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Table of Contents - continued

	PAGE
4.2.3 Departure Separation	112
4.2.4 En Route Passing and Crossing	132
4.2.5 Severe-Weather Avoidance/Traffic Separation	153
5.0 SYSTEM MECHANIZATION	169
5.1 Alternatives	169
5.1.1 Basic Traffic Data Source Considerations	169
5.1.2 Ground vs. Airborne Computational Considerations	171
5.1.3 Data-Link Considerations	174
5.2 Requirements	181
5.3 Upgraded Third Generation Based System	183
5.4 Airplane System	185
6.0 BENEFITS ANALYSIS	187
6.1 Assumptions	187
6.2 Independent Parallel Approach Monitor	189
6.3 Arrival In-Trail Spacing Control	202
6.4 Longitudinal Separation of Arrivals Monitor	209
6.5 Other CDTI Benefit Considerations	214

Table of Contents - continued

	PAGE
7.0 TEST SCOPE AND OBJECTIVES	217
7.1 Test Scope	217
7.2 Test Objectives	220
7.2.1 Flight Simulator Tests	220
7.2.2 Flight Tests	228
7.2.3 ATC Simulation Tests	229
7.2.4 Busy Terminal Area Flight Test	230
APPENDIX - LIST OF ABBREVIATIONS AND ACRONYMS	231
REFERENCES	233
BIBLIOGRAPHY	237

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1.2-1	Monitoring Displays	5
1.2-2	ATC Role Operational Situations	8
1.2-3	Departure Lateral Separation Display	9
4.1.1-1	Horizontal CDTI Traffic Range	33
4.1.1-2	Vertical CDTI Traffic Range	34
4.1.1-3	CDTI General TMA Operations Role	37
4.1.1-4	Typical CDTI General TMA Operations Monitor	39
4.1.2-1	CDTI Arrival Longitudinal Spacing Monitor Role	46
4.1.2-2	CDTI Arrival Longitudinal Spacing Monitor Role	48
4.1.3-1	Navigation Requirements	52
4.1.3-2	Communications/Surveillance Requirements	53
4.1.3-3	Parallel Approach Operations Assessment	55
4.1.3-4	CDTI Interfaces	58
4.1.3-5	Parallel Approach Monitor Logic	61
4.1.4-1	CDTI Runway Occupancy Monitor Role	72
4.1.4-2	CDTI Runway Occupancy Typical Display	75
4.2.1-1	Arrival Merging Functional Diagram	85
4.2.1-2	CDTI Arrival Merging Display	90
4.2.2-1	Spacing Variation due to TMA Speed Reduction	96
4.2.2-2	In-Trail Arrival Spacing Functional Diagram	103
4.2.2-3	CDTI Arrival In-Trail Spacing Control	108
4.2.3-1	ATA Noise Abatement Procedure	114
4.2.3-2	Northwest Airlines Noise Abatement Procedure	115
4.2.3-3	Departure Separation Functional Diagram	121
4.2.3-4	Longitudinal Separation (Vertical Separation) Display	128
4.2.4-1	Distribution of Air Carrier En Route Airspeeds	133

List of Illustrations - continued

FIGURE		PAGE
4.2.4-2	En Route Staffing Estimates	135
4.2.4-3	Control Logic Functional Flow	137
4.2.4-4	En Route Control Passing Logic	140
4.2.4-5	En Route Control Crossing Logic Flow	141
4.2.4-6	Typical Passing Geometry	144
4.2.4-7	Radius of Curvature Bank Angle	146
4.2.4-8	Required Passing Distance	147
4.2.4-9	En Route Crossing Maneuver	148
4.2.5-1	Severe-Weather Avoidance Functional Diagram	159
4.2.5-2	Severe-Weather Avoidance Display	164
5.1-1	CDTI Ownship Data-DABS 80-Bit Extended Word	176
5.1-2	Track Geometry Data - DABS 80-Bit Extended Word	177
5.1-3	Target Traffic Data - DABS 80-Bit Extended Word	178
5.3-1	CDTI UG3RD Mechanization Concept	184
6-1	Capacity Benefits from CDTI - Parallel Runway Operations	199
6-2	Delivery Accuracy - Capacity Sensitivity	204
6-3	Longitudinal Spacing Capacity Results (1980-2000 Total)	211
6-4	Longitudinal Spacing Results - Capacity Limited Airports	212
7.1-1	CDTI Test Scope	218

LIST OF TABLES

NUMBER	TITLE	PAGE
1.2-1	Summary Capacity Gains From CDTI (1980-1999 Gains Over Present ATC)	14
1.2-2	Summary Capacity Gain From CDTI (Implementation - Assumptions)	15
3.2-1	Selected CDTI Roles	28
4.1.3-1	Parameters Impacting Parallel Approach Operations	57
5.1-1	Computation and Data-Link Trade Matrix	173
6-1	Fifty Busiest Air Carrier Airports	191
6-2	Instrument Approaches at Applicable Airports	193
6-3	General Aviation Instrument Approaches	195
6-4	Airport Operations Increase	197
6-5	Runway Operations Rate Model Inputs	203
6-6	Longitudinal Spacing Benefits - Arrivals Only	205
6-7	Longitudinal Spacing Benefits - Mixed Operations	206
6-8	Arrival In-Trail Spacing Control Capacity Results - (3 Mile Spacing)	208
6-9	Longitudinal Spacing of Arrivals Monitor Capacity Results (2 Mile Spacing)	210
6-10	Potential Benefit Areas	215

1.0 INTRODUCTION AND SUMMARY

This report presents the results of the Cockpit Displayed Traffic Information (CDTI) study. The purpose of this study was to provide the planning base for conducting a flight test evaluation of an Electronic Horizontal Situation Indicator (EHSI) incorporating the position of other air traffic as derived from ground sensors. The study was accomplished for the Federal Aviation Administration Office of Systems Engineering Management by the NASA Terminal Configured Vehicle program and their contractor. The DOT Transportation Systems Center acted as technical monitor to the contractor.

The objectives of this study were to: (1) define and scope a system concept for an airborne information display utilizing ground derived ATC and ATC-related information. (This concept to be based on measurable potential ATC system benefits that are amenable to experimental verification via simulation and flight tests.); and (2) prepare an outline of a simulation and flight test program which includes the NASA 515 aircraft, the Langley Research Center traffic simulation and other aircraft and simulations. Testing in a busy terminal area was also to be planned.

The general approach was to review the extensive work of other investigators on the CDTI and related concepts, formulate operational concepts for how various roles could be used in the Upgraded Third Generation ATC system* (and in realistic terminal area traffic situations), and identify the simulation and testing necessary to evaluate the performance achievable with CDTI. The procedure for selecting roles for concept formulation was to develop a list of the roles previously proposed by various investigators, and use the recommendations of a government/industry CDTI working group to identify which of these roles most likely could contribute to improved operations in future terminal area ATC systems. The potential benefits of these roles to ATC, airplane operations and others were estimated to aid in the selection process. The material reviewed and used in concept formulation is listed in the bibliography.

* The time required to test and develop a CDTI operational capability might end up with initial use of the CDTI in the later stages of the Upgraded Third Generation or even in the following generation of ATC systems.

1.1 Introduction

Various investigators over the years have studied the incorporation of a display of the surrounding airborne traffic situation into the airplane cockpit for use in operation in the air traffic control system (see bibliography). This device, which has previously been called an Airborne Traffic Situation Display (ATSD), is now referred to as the Cockpit Displayed Traffic Information (CDTI) function when traffic information is added to an Electronic Horizontal Situation Indicator (EHSI).

A cockpit display presenting information on surrounding traffic has been proposed for various roles. These include:

- 1) As a pilot assurance device by displaying the traffic situation; thus, lending understanding and confidence in the ATC information and actions of other pilots. When the pilot detects a questionable situation, he would request ATC to assess it and provide control instructions to resolve the problem.
- 2) As a collision avoidance system which would allow evasive action should a blunder by either ATC or another pilot result in a collision situation.
- 3) As an ATC control element which would allow each pilot to determine the flight path he should follow to solve the traffic situation (as in VFR flight). This has been called Distributed Management.
- 4) As a navigation/guidance device. (This requires presenting information other than traffic.)
- 5) As a communication readout presenting either text or pictorial data (e.g., weather reports, IPC instructions, weather contours, etc.).

Previous investigations have considered these roles for various phases of flight (takeoff, departure, en route, descent, approach, final approach,

landing, and taxi); and for various ATC systems (the Upgraded Third Generation and distributed management systems).

These concepts have all focused on a cathode ray tube display in the cockpit and implied that the pilot would assess the situation directly from the relative traffic information. However, most roles would undoubtedly require on-board data processing to assist in effectively accomplishing the function.

1.2 Summary

Specific operational and system concepts were formulated for the selected CDTI roles and simulation and flight test scope and objectives were defined. Also, some general conclusions and recommendations on the application of Cockpit Displayed Traffic Information to operations in the Upgraded Third Generation ATC system were developed.

1.2.1 Operational Concepts

After thoroughly reviewing terminal area operations as planned in the Upgraded Third Generation ATC system, operational concepts for the CDTI roles (traffic monitoring and air traffic control) were formulated.

During the examination of the logic for using a CDTI, several ground rules were assumed.

- 1) Only operations depending upon data (such as a relative position) on proximate traffic are to be considered. Concepts which require the display of 2D, 3D or 4D paths but not proximate traffic for ownship navigation are considered to be in the domain of EHSI or other systems; but not CDTI roles.
- 2) In the UG3RD operational concepts should not depend upon air to air coordination. Pilot initiated air to air communication could interfere with necessary ATC messages.

- 3) The CDTI should not be considered as an airborne "collision avoidance system."
- 4) ATC would retain the separation assurance responsibility.
- 5) When the CDTI is used to do tasks normally done by ATC, a specific clearance would be negotiated with ATC for each instance.

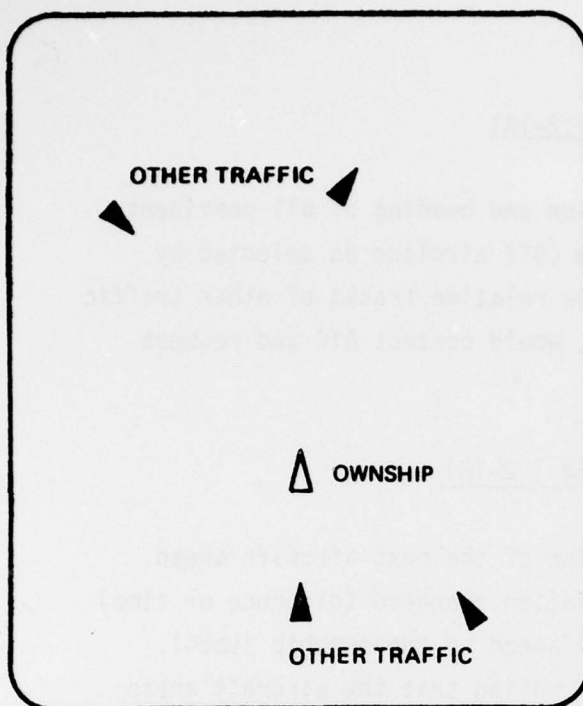
1.2.1.1 Traffic Monitor (Pilot Assurance) Roles

The CDTI can provide the pilot the capability to monitor the surrounding traffic situation: either to generally monitor the total picture or selectively monitor critical operations. In the monitoring role the pilot would look for situations in which the separation "appears" to be in danger of going below the accepted safe value and request ATC to review and rectify the situation as necessary.

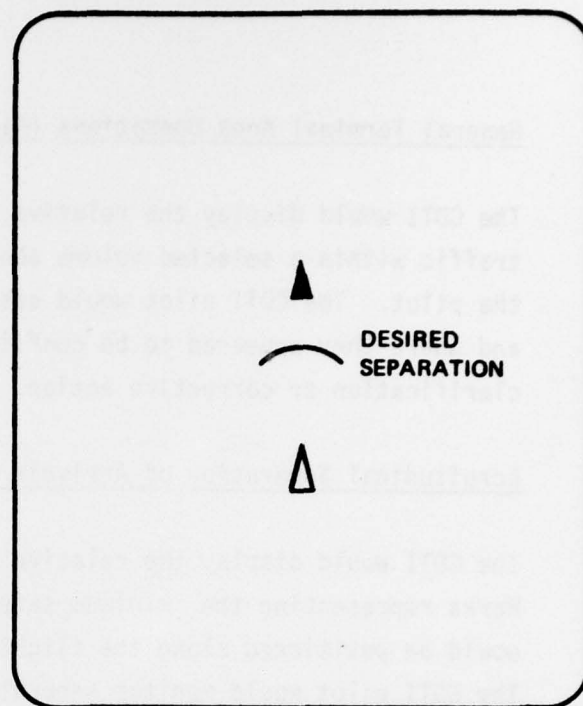
The CDTI monitoring in the Upgraded Third Generation ATC system would be an additional means to assure traffic separation. Other means include:

- 1) ATC traffic planning to preclude conflicts
- 2) Automated conflict alert/resolution
- 3) Intermittent positive control
- 4) Possibly an airborne collision avoidance system.

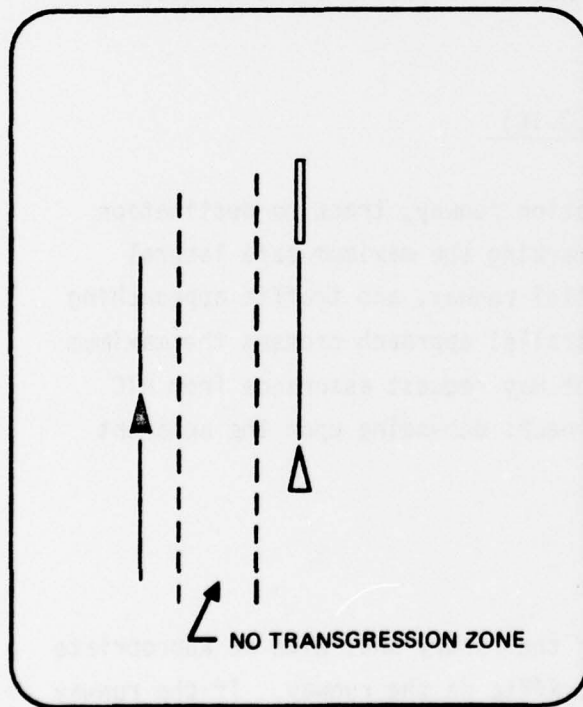
Concepts were formulated for four monitoring roles. Figure 1.2-1 shows (conceptually) sketches of nominal display formats for these roles. No attempt was made to optimize displays in this study. This task is a major objective of the test program. The CDTI pilot would have controls to allow selection of the appropriate display. Data blocks would be available for each target, showing flight identity, ground speed, altitude and direction of climb or descent (if changing altitude). The data block presentation and content would be pilot controllable.



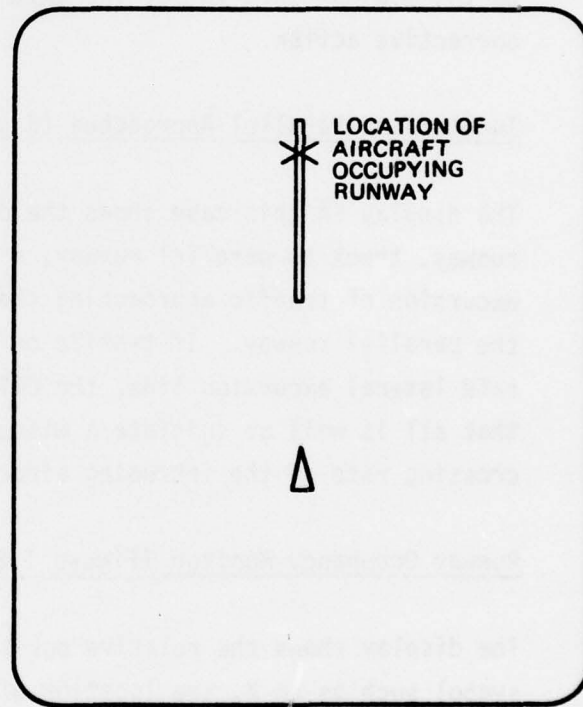
A. GENERAL TMA OPERATIONS



B. LONGITUDINAL SEPARATION OF ARRIVALS



C. INDEPENDENT PARALLEL APPROACHES



D. RUNWAY OCCUPANCY MONITOR

FIGURE 1.2-1 MONITORING DISPLAYS

General Terminal Area Operations (Figure 1.2-1A)

The CDTI would display the relative position and heading of all pertinent traffic within a selected volume about the CDTI airplane as selected by the pilot. The CDTI pilot would assess the relative tracks of other traffic and where they appeared to be conflicting, would contact ATC and request clarification or corrective action.

Longitudinal Separation of Arrivals (Figure 1.2-1B)

The CDTI would display the relative position of the next aircraft ahead. Marks representing the minimum safe separation standard (distance or time) would be positioned along the flight track ahead of the ownship symbol. The CDTI pilot would monitor separation by noting that the aircraft ahead was beyond the minimum safe separation marks. Should separation decrease to the minimum safe value, the CDTI pilot would contact ATC and request corrective action.

Independent Parallel Approaches (Figure 1.2-1C)

The display in this case shows the destination runway, track to destination runway, track to parallel runway, a line marking the maximum safe lateral excursion of traffic approaching the parallel runway, and traffic approaching the parallel runway. If traffic on the parallel approach crosses the maximum safe lateral excursion line, the CDTI pilot may request assurance from ATC that all is well or initiate a missed approach: depending upon the apparent crossing rate of the intruding aircraft.

Runway Occupancy Monitor (Figure 1.2-1D)

The display shows the relative position of the runway and, with an appropriate symbol such as an X, the location of any traffic on the runway. If the runway is not cleared by the missed approach point on arriving, the CDTI pilot would go around. For takeoff, the pilot would not start his takeoff roll unless the

runway was clear. Taxiing traffic can monitor an active runway before using or crossing it in conditions of poor visibility.

1.2.1.2 Air Traffic Control Roles

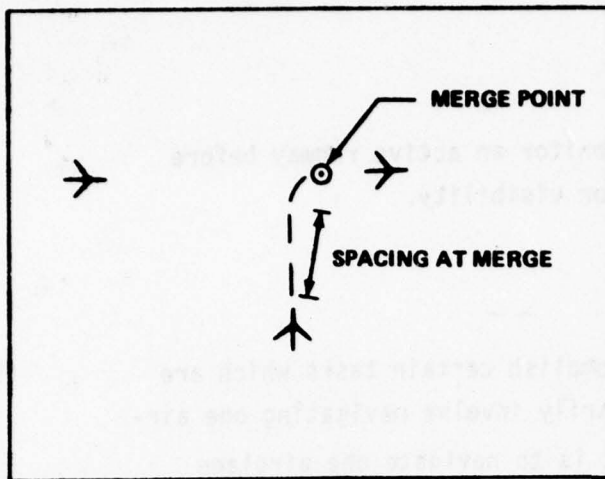
The CDTI can be used by the pilot to accomplish certain tasks which are presently done by ATC. These tasks primarily involve navigating one airplane relative to another. When the task is to navigate one airplane relative to another, a pilot using CDTI should be able to do this as well as or better than the controller: thus, relieving the controller of a significant workload item.

Each CDTI Air Traffic Control role to be considered can be expressed as an ATC request that the CDTI airplane maintain some specified separation or spacing from another specified aircraft until some specified limit is reached. More complex roles were considered and rejected because they involved either:

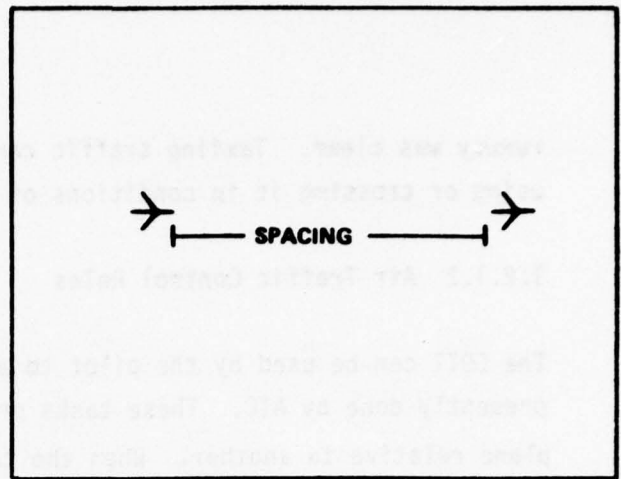
- 1) a comprehensive understanding of the traffic situation including destinations, priorities and intended maneuvers, which only the ATC system now has, or
- 2) only 2D, 3D or 4D navigation ownship tasks without any relative airplane-to-airplane navigation.

Figure 1.2-2 shows the operational situations in which the selected CDTI ATC roles were considered.

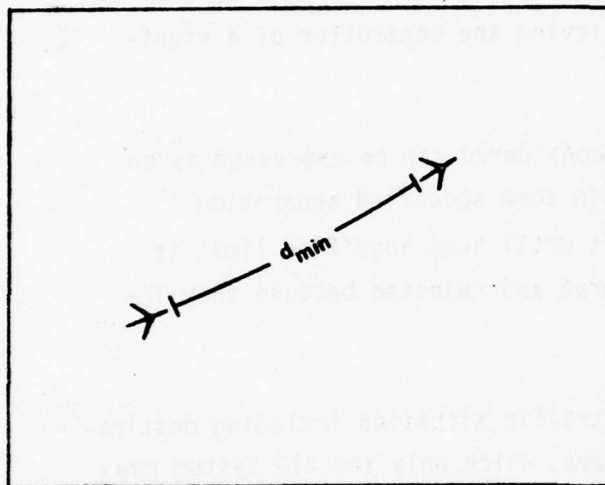
For each of these roles, the display would show: (1) ownship position, (2) the position and heading of the target aircraft, (3) appropriate marks or leaders indicating the desired spacing or minimum separation, and (4) an indication of the rate at which the separation was changing. Appropriate data blocks would be available and displayable under pilot control. Figure 1.2-3 shows an example



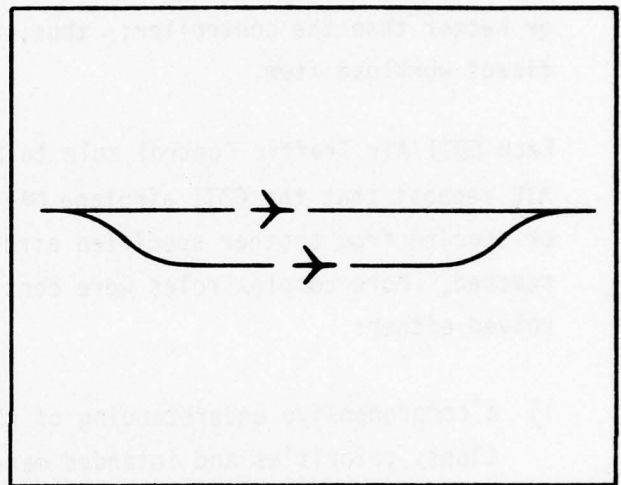
A. ARRIVAL MERGING



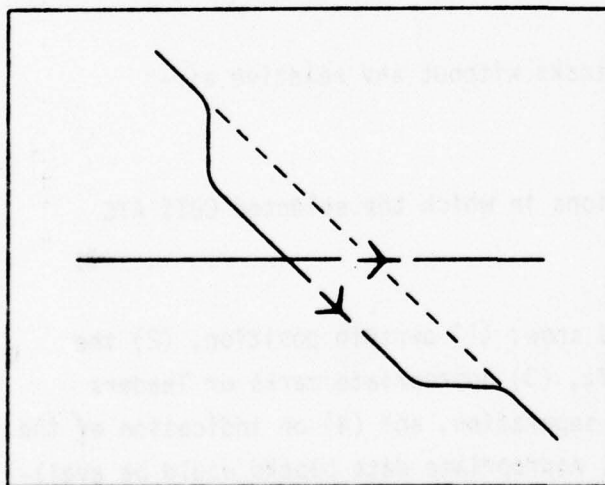
B. ARRIVAL IN-TRAIL SPACING



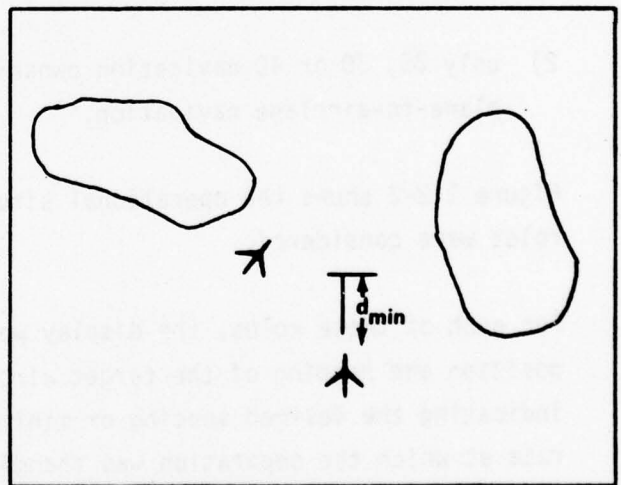
C. DEPARTURE SEPARATION



D. ENROUTE PASSING



E. ENROUTE CROSSING



F. SEVERE WEATHER AVOIDANCE SEPARATION.

FIGURE 1.2-2 ATC ROLE OPERATIONAL SITUATIONS

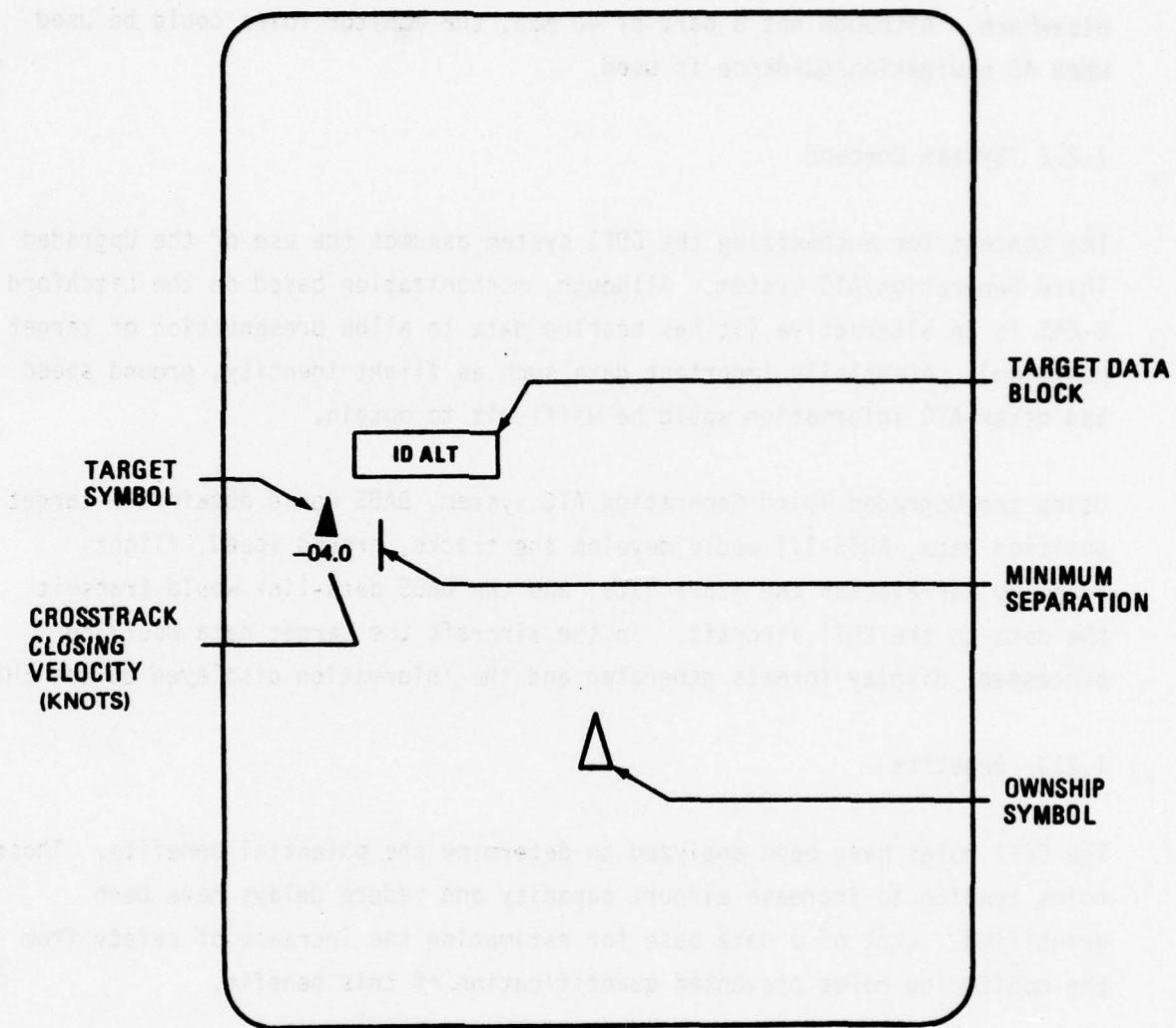


FIGURE 1.2-3 DEPARTURE LATERAL SEPARATION DISPLAY

display for departure separation using a lateral offset.

Although it developed that this concept does not fundamentally involve the relative position of other traffic, the concept of using 4D navigation/guidance equipment in the metering and spacing environment was also studied. Therefore, the concept is described in Section 4, but is not reported elsewhere. Although not a part of 4D M&S, the monitor roles could be used when 4D navigation/guidance is used.

1.2.2 System Concept

The concept for mechanizing the CDTI system assumes the use of the Upgraded Third Generation ATC system. Although, mechanization based on the Litchford B-CAS is an alternative (it has bearing data to allow presentation of target position), potentially important data such as flight identity, ground speed and other ATC information would be difficult to obtain.

Using the Upgraded Third Generation ATC system, DABS would obtain the target position data, ARTS-III would develop the tracks, ground speed, flight identity correlation and other data, and the DABS data-link would transmit the data to the CDTI aircraft. In the aircraft the target data would be processed, display formats generated and the information displayed on the EHSI.

1.2.3 Benefits

The CDTI roles have been analyzed to determine the potential benefits. Those roles tending to increase airport capacity and reduce delays have been quantified. Lack of a data base for estimating the increase of safety from the monitoring roles prevented quantification of this benefit.

Various investigators have developed performance claims for the different CDTI roles. The objective of the benefits analysis was to determine the potential benefits if the investigators performance claims are accurate. The

following assumptions formed the basis for the benefits:

- 1) Intended function will be accomplished (for example, if the CDTI permits 2 mile spacing a reduction will be implemented).
- 2) All requirements (accuracy, data rate, display, etc.) integral to accomplishing the function will be met.
- 3) Suitable ground systems supportive of the benefit can and will be developed.
- 4) Benefits are calculated only for air carrier airports and airplanes.
- 5) Benefit is all attributed to CDTI even though other areas must be improved to realize the gain (wake turbulence reduction, airport surface improvements, etc.).

The purpose was to identify those roles with significant potential benefits to justify further testing to accurately determine the performance achievable by each of these roles in a realistic operational environment. At some time the benefits and cost of the promising roles must be compared to the benefits and costs associated with alternative methods for providing the same function.

In many cases, the total benefit for an improved operation should not be credited to CDTI. The benefits calculated for a CDTI role, such as reduced delays or increased airport capacity, involve not only the improved performance provided by the CDTI, but other non-CDTI improvements. Thus, the other improvements necessary to obtain the benefit must be recognized. Actually, the Upgraded Third Generation ATC system is planned to provide these benefits without CDTI. For example, two mile separation and 2,500 feet parallel independent approaches are stated goals.

The measures of benefit used are increased operations and/or reduced delay at air carrier airports. Savings for the 1980 to 1999 time period are calculated.

Airports analyzed are all those in which demands will reach practical annual capacity during the next 30 years. Twenty-four airports are included. These accounted for half of 1975 air carrier operations and 90% of the airline experienced delay. FAA methods for determining annual capacity and delay are used. It is postulated that at annual capacity no further operations occur. This sets an upper limit on the maximum delay per operation that can be experienced at any airport.

Benefits were calculated for the following roles:

Independent Parallel Approach Monitor

Some airspace users have indicated that an independent parallel approach monitoring would be necessary for the 2,500 foot minimum runway separation proposed for the Upgraded Third Generation ATC system using MLS and automatic approach monitoring. This will increase the IFR capacity of airfields with parallel runway separations which are 2,500 feet or greater, but less than today's requirement (4,300 feet). Assuming that CDTI is required as a prerequisite to accepting 2,500 feet, it was estimated that six airports would benefit from this capability with a 20 year (1980 to 1999) gain of 1,735,000 operations along with a delay reduction of 3,765,000 minutes.

Arrival In-Trail Spacing Control

ATSD experiments have developed data indicating that pilots could use CDTI to control spacing between arrivals to an accuracy of 3 seconds (one sigma). These results are independent of the arrival ATC method used. A method for controlling arrivals and using the 3 second accuracy must be developed. The assumption is that this more accurate control will provide increased arrival rates with the same longitudinal separation requirements as today. Gains are 18,790,000 operations and 33,790,000 minutes delay reduction over the present ATC system at 24 heavily loaded airports. Gains over an assumed improved ATC environment are 4,010,000 operations and 31,065,000 minutes delay reduction.

Longitudinal Separation of Arrivals Monitor

Certain airspace users have indicated that additional longitudinal separation monitoring would be needed to operate at the 2 nautical mile longitudinal separation proposed for advanced M&S arrival operations. Benefits in this case are 23,570,000 operations increase and 80,640,000 minutes delay reduction over present ATC. For the assumed ATC implementation schedule, an increase of 1,715,000 operations was obtained and a delay reduction of 40,775,000 minutes was estimated.

Summaries of the results, if CDTI is available in 1980 are given in Tables 1.2-1 and 1.2-2.

Table 1.2-1 gives the 20 year gains compared to the present ATC environment as the baseline. Table 1.2-2 shows gains over planned FAA improvements for the next 20 years. The following definitions and implementation schedule were used for Table 1.2-2.:

Basic M&S (1985)

- ARTS tracking (speed, heading and altitude commands displayed)
- Computer derived separation monitoring

Advanced M&S (1990)

- DABS tracking
- MLS
- Data-link communications
- Area navigation

Closed-Loop-Time Control (1995)

- Ground schedule and separation monitoring
- Threshold time to 4D airplanes.

Other assumptions relative to the implementation dates would give different results.

Details of the results and analysis follow in the benefits section of this report.

ROLE	OPERATIONS INCREASE	DELAY REDUCTION (MINUTES)	
		TOTAL	PER OPERATION AT AFFECTED AIRPORTS
INDEPENDENT PARALLEL APPROACH MONITOR (1)	1,735,000	3,765,000	0.16
ARRIVAL IN-TRAIL SPACING CONTROL (2)	18,790,000	33,790,000	0.47
LONGITUDINAL SEPARATION OF ARRIVALS-MONITOR (2,3)	23,570,000	80,640,000	0.85

(1) 6 Airports Capacity Limited

(2) 24 Airports Capacity Limited

(3) Assuming present ATC Maintains 3 Mile Separation

(4) See text pages 10 and 11 for further assumptions

TABLE 1.2-1 SUMMARY CAPACITY GAINS (1980-1999 GAINS OVER PRESENT ATC)

ROLE	BENEFIT (1980 - 1999) (1)		
	OPERATIONS INCREASE	DELAY REDUCTION (MINUTES)	
		TOTAL	PER OPERATION AT AFFECTED AIRPORTS
INDEPENDENT PARALLEL APPROACH MONITOR (2)	1,735,000	3,765,000	0.16
ARRIVAL IN-TRAIL SPACING CONTROL (3)	4,010,000	31,065,100	0.28
LONGITUDINAL SEPARATION OF ARRIVALS-MONITOR (3)	1,715,000	40,775,000	0.31

(1) Assuming the Following Schedule:

CDTI - 1980
Basic M & S - 1985
Advanced M & S - 1990
Closed-Loop - Time Control - 1995

(2) 6 Capacity Limited Airports

(3) 24 Capacity Limited Airports

(4) See text pages 10 and 11 for further assumptions.

TABLE 1.2-2 SUMMARY CAPACITY GAIN (IMPLEMENTATION ASSUMPTIONS)

1.2.4 Recommended Test Scope and Objectives

A comprehensive test program is recommended consisting of a sequence of four simulation/test configurations with program assessment between configurations. The four simulation/test configurations are:

- 1) A CDTI airplane flight simulator;
- 2) A CDTI flight test airplane operating in a limited simulated traffic environment;
- 3) A real-time terminal area ATC simulator using CDTI airplane simulators;
- 4) A CDTI flight test airplane operating in a busy terminal area.

The objectives of the flight simulation and initial flight testing are to:

- 1) Develop the design of the airborne CDTI elements and operational procedures to satisfy a practical operational system;
- 2) Determine which roles are operationally feasible considering both flight and ATC operations;
- 3) Measure the achievable performance as a basis for refining the benefits estimates.

These tests would be followed by a comprehensive terminal area ATC simulation to evaluate the ATC aspects of CDTI and a busy terminal area flight test to gain CDTI experience in a live traffic environment.

1.2.5 Conclusions

The fundamental conclusions of this study are the CDTI role concepts presented in Section 4.0.

1.2.6 Recommendations

The fundamental recommendations of this study are the test requirements. Beyond these, the following general recommendations are provided.

- 1) All future simulation and testing should be done in a realistic traffic situation and ATC environment to preclude misleading conclusions that simpler testing can promote.
- 2) Future research on CDTI should be directed toward those roles which show the most promise of "contributing" to ATC capabilities.
- 3) The test program recommended in this study should be completed before further effort is made to operationally implement CDTI capabilities.
- 4) An analysis of the data-link system to support CDTI operations should be completed at an early date.

2.0 ATC ENVIRONMENT

The CDTI would operate in the Upgraded Third Generation (UG3RD) ATC System. The major features being developed to upgrade the third generation ATC system (Reference 1) are:

- o Discrete Address Beacon System (DABS)
- o Intermittent Positive Control (IPC)
- o Flight Service Station (FSS) Automation
- o Upgraded Automation of ARTCC's and TRACON's
- o Airport Surface Traffic Control (ASTC)
- o Wake Vortex Avoidance System (WVAS)
- o Area Navigation (RNAV)
- o Microwave Landing System (MLS)
- o Aeronautical Satellites (AEROSAT)

Considering the time required to develop various UG3RD features, the ATC system capabilities are expected to be as follows:

Terminal Area ATC

Surveillance - An improved ATCRBS will be used until replaced with the Discrete Address Beacon System (DABS). DABS will provide increased target position accuracy; improved reliability; and improved discrimination capability. In addition, a two-way data-link capability and selective addressing features are to be provided.

ARTS-III - The ARTS-III system will be upgraded with advanced automation features which include:

- o Metering and Spacing (M&S) - The basic M&S capability will allow for time scheduling to the runway with one or more time fixes between the initial approach fix (IAF) and the runway. The capability provided to the controller will include automatic calculation of suggested time-to-

turn commands (to a heading or waypoint); and altitude and speed assignments to assure meeting the arrival time schedules. Communication in the basic M&S will be via VHF voice.

The advanced M&S capability will more completely handle terminal area operations including departures. When data-link becomes available, it is contemplated to transmit control instructions directly to the aircraft.

- o Automated Conflict Alert/Resolution - The automated conflict alert capability provides a capability for automatic prediction of conflicts between tracked aircraft based on altitude and safe separation criteria. Detected conflicts will cause controller alerting. Future extension of this capability will result in a capability to fully automate the separation of controlled traffic. This will be accomplished by encoding the resolution rules for automatically-detected track conflicts, i.e., automatically generating revised altitude and heading assignments to meet the prescribed track separation criteria in horizontal miss distance and altitude. The capability will also provide for returning the aircraft to the desired assignments after the potential for conflict has passed. The control instructions will be sent to the aircraft via data-link when that capability becomes available.
- o Control Message Automation - The gradual deployment of DABS to cover all terminal hub areas and the busier en route airspaces between these hubs will provide a high capacity, ground-air-ground data-link between ATC facilities and properly equipped aircraft with coverage over much of the nation. Within this environment, the data-link delivery of ATC clearances, assignments, and advisories for most IFR operations can be anticipated. Non-routine clearances and exceptions taken by the pilot will be handled via either voice radio or manual data entry devices.

- o Minimum Safe Altitude Warning (MSAW) - The MSAW capability will automatically advise the controllers when tracked aircraft with Mode C are descending below minimum safe altitudes in the terminal area. Initial capability will alert the traffic controller of a minimum safe altitude violation. Eventual capability is expected to automatically provide MSAW advisories to the pilot via data-link.
- o Parallel Approach Monitor - The present parallel approach monitoring capability will be updated to provide improved surveillance and automated approach monitoring to support simultaneous approaches on parallel runways spaced as close as 2500 feet.
- o Intermittent Positive Control (IPC) - IPC is a totally automatic ground-based service which provides pilots with proximity information on other aircraft and provides collision avoidance service to avert an impending collision. The objectives of the IPC service are: (1) provide VFR/VFR collision protection; (2) provide VFR/IFR collision protection; and (3) serve as a backup to the ATC system by providing IFR/IFR collision protection in the event of an ATC system failure.

Microwave Landing System (MLS) - The MLS will provide a capability for multiple glideslopes and curved approach paths in addition to improved navigation as compared to ILS.

Area Navigation (RNAV) - The RNAV capability will provide a system capability for direct paths via preselected waypoints improving the operational efficiency and reducing workload.

En Route ATC

Surveillance - The surveillance system is expected to evolve from ATCRBS to DABS as discussed under Terminal Area Surveillance.

NAS - The NAS computers are expected to have the following increased automation features under the UG3RD system:

- o Automated Conflict Alert/Resolution
- o Control Message Automation (using data-link)
- o En Route Metering
- o Intermittent Positive Control (IPC)
- o Minimum Safe Altitude Warning (MSAW)

Area Navigation (RNAV) - RNAV capability as discussed under Terminal Area, above, will be available.

Ground ATC

The Airport Surface Traffic Control (ASTC) system will provide improved radar surveillance and simple stop-go and visual signals to the pilot for control of movement on the airport surface. Automation of some of the control functions, and improved surveillance, displays, and facilities for the local and ground controllers are planned for the future.

Oceanic ATC

The present HF communication system without surveillance will continue into the foreseeable future. The AEROSAT program is expected to recommend an operational satellite-based communication and surveillance system at an indefinite point in time.

3.0 ROLE IDENTIFICATION

All of the roles proposed by previous investigators which appeared to have application in the upgraded third generation ATC system were identified and developed into a systematic list of candidate roles. This list of candidate roles was submitted to a government/industry CDTI working group for their evaluation. Based on the commentary of the CDTI working group, those roles with the most promise were identified for concept formulation.

3.1 Candidate Roles

The candidate CDTI roles provided for the CDTI working group's consideration were divided into three categories dependent on the intended use. These were: (1) Traffic Monitor (Pilot Assurance); (2) Airborne Collision Avoidance; and (3) Air Traffic Control. Each category is discussed below.

Traffic Monitor (Pilot Assurance)

This category includes the pilot assurance roles. In these roles, the pilot would observe the surrounding traffic to detect situations where the separation may go below the safe minimum separation value if the flights continue according to present plans (a conflict may occur). Generally, the pilot is looking for blunders by ATC or other pilots. This is the voice communication "party line" substitute. When it is detected that a conflict may occur, the pilot would bring this to the attention of ATC for resolution.

This function is in addition to all normal ATC functions including surveillance and advanced automation features as discussed in Section 2.

Specific traffic monitor roles include:

- 1) General TMA Operations - This role provides the CDTI airplane the capability to monitor the airplanes generally in its vicinity in the TMA. This role would allow a general understanding of the surrounding traffic situation.
- 2) Longitudinal Spacing of Arrivals - This role provides a capability for monitoring the spacing with adjacent airplanes on an arrival path.
- 3) Independent Parallel Approaches - This role provides the capability to monitor traffic on the adjacent parallel path during simultaneous approaches to independent parallel runways.
- 4) Airport Surface Taxiing - This role provides a capability to monitor pertinent traffic during surface movement operations.
- 5) En Route - This role provides the capability for monitoring pertinent traffic during en route operations such as changing altitude, passing, crossing, and merging.
- 6) Overocean - This role is the same capability as the en route role above, except that due to lack of surveillance and reliable communications, pilots may be required to solve their own problems and CDTI mechanization will be different.
- 7) Runway Occupancy Monitor - This role is to provide a capability for the CDTI airplane to monitor active runway occupancy situations during taxiing, landings or takeoffs.

Airborne Collision Avoidance

This category of role differs from the traffic monitor category in that the available reaction time is too short for ATC involvement and the system must meet the requirements of an airborne CAS. This means that suitable detection reliability, response times, available data, and cooperative escape mechanisms must be available.

These roles would be parallel to ground ATC functions (e.g., IPC, which backs up conflict alert/resolution service) bringing attendant problems such as "who's in charge", etc. In this role the pilot would observe the surrounding traffic to detect possible collision situations. These are situations where an ATC or pilot blunder has produced a condition in which a collision is likely unless immediate evasive action is taken. The minimum safe separation has already been violated or its violation is inevitable. The pilot would compare the flight track information on all tracks which could possibly conflict with that of his own aircraft and detect any potential collision situations. He would then determine a safe escape maneuver and execute it. This role must provide for a high probability of detection of a collision situation with a low probability of causing action to be taken in an otherwise safe situation (false alarm). The system (pilot and/or equipment) must indicate the safe maneuver necessary to successfully avoid the collision without producing an equal or greater collision hazard with other traffic.

Specific airborne collision avoidance roles include:

- 1) General TMA Operations - This role is to provide a General TMA airborne CAS capability using the CDTI.
- 2) Longitudinal Spacing of Arrivals - This role is to provide an airborne CAS capability for situations in which a collision is imminent due to loss of longitudinal spacing.
- 3) Independent Parallel Approaches - This role is to provide an airborne

CAS capability for the special case of simultaneous independent approaches to parallel runways.

- 4) Airport Surface Taxiing - This role is to provide a cockpit capability to detect a potential collision situation sufficiently in advance that no special last moment maneuvers are required during surface operations, particularly in low visibility conditions.
- 5) En Route - This role is to provide a CDTI based airborne collision avoidance capability during en route operations.
- 6) Overocean - This role is to provide a CDTI-based airborne collision avoidance capability during oceanic operations.

Air Traffic Control

In this role the pilot would observe the surrounding traffic and maneuver his airplane to accomplish functions which under IFR flight are now accomplished by ATC. ATC would provide certain basic guidance data such as arrival sequence, and route and maneuver-airspace constraints. For example, in a passing situation, ATC would instruct the pilot when to take a specific parallel offset which would provide safe separation in case of system failure and the display would be used to monitor the passing maneuver. In this type of operation, functions are unacceptable that divide controller/pilot responsibilities in a way that either party does not know exactly what the other is going to do. Course deviations must be defined and agreed to by both parties. These roles complement functions presently provided by the ATC controller, but are otherwise expected to operate in conjunction with the ATC system. In this regard, new ATC functions and control responsibility interfaces must be conceived and implemented. An example would be aiding ATC in achieving and maintaining a desired spacing to another aircraft.

Specific air traffic control roles include:

- 1) Arrival Merging - This role is to provide a self-merging capability using the CDTI device in conjunction with ATC-provided objectives, including sequence.
- 2) Arrival In-Trail Spacing Control - This role is to provide a self-spacing capability based on an ATC-supplied desired spacing function.
- 3) Departure Separation - This role is to provide for departure self-separation based on ATC-supplied clearances.
- 4) En Route Passing and Crossing - This role is to provide for airplane passing and crossing situations based on ATC-supplied clearances which provide safe separation from the other traffic.
- 5) En Route Longitudinal and Lateral Spacing Control - This role provides the capability for an airplane to achieve self-spacing based on ATC-supplied spacing objectives.
- 6) Separation During Severe-Weather Avoidance - This role is to provide a capability for self-separation while avoiding severe-weather cells.
- 7) Separation While Taxiing - This role is to provide the capability for self-separation during taxiing operations based on ground control supplied objectives.

3.2 Selected Roles

The CDTI working group met on November 13, 1975, and discussed the candidate roles. A principal conclusion of the meeting was that the CDTI should not be considered as a collision avoidance system and the collision avoidance roles are not applicable to this study. Upon considering the CDTI working group comments, the roles listed in Table 3.2-1 were selected for further study.

TABLE 3.2-1
SELECTED CDTI ROLES

TRAFFIC MONITOR ROLES

General Terminal Area Operations
Longitudinal Separation of Arrivals
Independent Parallel Approaches
Runway Occupancy Monitor

AIR TRAFFIC CONTROL ROLES

Arrival Merging
Arrival In-Traill Spacing
4D Application to M&S Environment
Departure Separation
En Route Passing and Crossing
Separation During Severe-Weather Avoidance

4.0 INDIVIDUAL ROLE CDTI CONCEPTS

The concept for each individual CDTI monitor and air traffic control role is described including the problem statement, solution approach, discussion, operational concept, potential benefits, potential problem areas, and test scenario considerations.

4.1 Traffic Monitor Roles

The traffic monitor roles are characterized by their use only for monitoring the situation rather than a device by which control actions and/or maneuvers are determined. If the monitoring identifies an unusual or hazardous situation, the CDTI pilot communicates with the ground system for resolution.

Four specific monitor roles were considered for concept formulation. These are:

- 1) General TMA operations;
- 2) Longitudinal Separation of Arrivals;
- 3) Independent parallel approaches to close-spaced runways; and
- 4) Runway occupancy monitor.

4.1.1 General TMA Operations

The CDTI monitor role for general terminal operations provides the pilot with an overview of all TMA traffic of concern to the progress and safety of his aircraft. The assumption is that a pilot with more pertinent information about his surrounding (or threat) traffic will perform in a safer manner and contribute to improved overall system performance.

4.1.1.1 Problem Statement

The pilot today operates with limited information of his surrounding traffic situation. During instrument conditions he cannot visually detect other

traffic; while during visual conditions there is no assurance that he will detect traffic of concern. The voice air-ground communications, "party line", provides other cues to surrounding traffic; requiring the pilot to understand who said what and build a mental picture of the situation. Perhaps the most helpful cues are the voice advisories from the controller which direct attention to particular traffic of concern. However, this radar traffic information service: (1) is not mandatory; (2) may be terminated at controller's discretion at any time; (3) may indicate target radar slant range, but not altitude; (4) azimuth data must be corrected for the difference between track and heading angles (i.e., in wind conditions); and (5) is communications workload intensive. In summary, the pilot has, at best, an incomplete picture of the airplane traffic which may affect him.

Future developments such as data-link will eliminate data presently available from the voice party-line. This situation thus poses the problem of how to provide the pilot confidence in the safety of the traffic situation in which he is flying and some means of assuring him that either ATC or another pilot has not made an error.

4.1.1.2 Solution Approach

The general solution is for the pilot to use a cockpit display showing the relative position of surrounding traffic to monitor the traffic situation.

4.1.1.3 Discussion

A CDTI traffic monitor can be considered as: (1) a pilot assurance device to replace or complement the voice party-line and visual cues; or (2) a pilot warning system. Each of these functions may impose different requirements on the CDTI display content.

The party-line CDTI display can provide the pilot with a visual presentation of the traffic in his immediate vicinity to improve his comprehension of the traffic situation in which he is being controlled. In addition, the display

of range, altitude and bearing from his airplane can aid the pilot in visually locating traffic. This may reduce the time spent "heads-up" and improve the probability of timely acquisition of significant traffic. Thus, a CDTI device could potentially reduce cockpit tension and workload, and with the improved acquisition probability may have safety benefits; either with or without CAS or IPC.

A CDTI monitor could have advantages in both a voice or a data-link environment. In the voice environment, it can reduce the need for radar traffic advisory service. In the data-link environment, it could provide the pilot assurance now provided by the party-line voice cues.

In using a CDTI in the pilot assurance function, a number of human factor and workload questions still remain unresolved. For example, the CDTI cues on surrounding traffic would need to be visually acquired, rather than in an aural manner, which in turn has a different alerting and senses-sharing relationship than the present techniques. It is also possible that the pilot would be aware of more traffic near him than he perceives today and additional cockpit tension might result. Controller-pilot relationships for traffic advisory would no doubt change and hence would need to be formulated, tested and evaluated.

The second potential traffic monitor function is as a pilot warning system. Reference 2 states "A system which detects the presence of intruder aircraft is broadly defined as a pilot warning system. In addition to detection, it may also give a crude indication of the intruder's position either by a bearing indication, a bearing-elevation measurement or even possibly a range or range-altitude indication.". This reference indicates that the functions of threat evaluation, avoidance maneuver determination and monitoring are left to the pilot. However, in the definition of the CDTI traffic monitor roles, the responsibility for avoidance maneuver determination is placed with the controller to preclude problems with pilot derived maneuvers.

The essential question involved with CDTI use as a pilot warning system is

whether adequate visual cues exist which could allow the pilot to identify a potential problem and make a timely inquiry of the controller and yet have a sufficiently low number of false alarms. For identifying a potential problem (NOTE: This is problem identification only and the discussion does not imply that this is, or can be, a collision avoidance system) the existence of constant bearing along with diminishing range is a visual cue indicative of a collision course for the rectilinear case (i.e., constant velocity vectors). It can be shown that this constant bearing angle is linearly projected onto the horizontal plane of the CDTI, and thus can yield a constant angle visual cue to the pilot. No such simple criteria has been identified for the curvilinear case. If a CDTI pilot is to detect all potential problems, a solution to the visual cues for detecting the curvilinear case must be found.

If the CDTI used as a general TMA operations monitor were to be used to display all traffic which could be a threat within the next "n" seconds, a τ^* criteria for both range and altitude would be the appropriate selection gate to determine which airplanes should be displayed. In addition, display of very close traffic which would not necessarily trigger the tau gates should be shown. The display scale distance and altitude ranges as a function of closing velocity, for various reaction times, are shown on Figures 4.1.1-1 and 4.1.1-2. The reaction times are the times until the stated separation criteria may be violated. The implication of the charts is that the CDTI scale would require 22 n.mi. range and 11,000 feet altitude to cover all TMA situations.

The CDTI general TMA monitor role is then reduced to one of pilot assurance by showing all airplanes in the immediate proximity of the CDTI aircraft.

* τ is range divided by range rate and indicates time to collision.

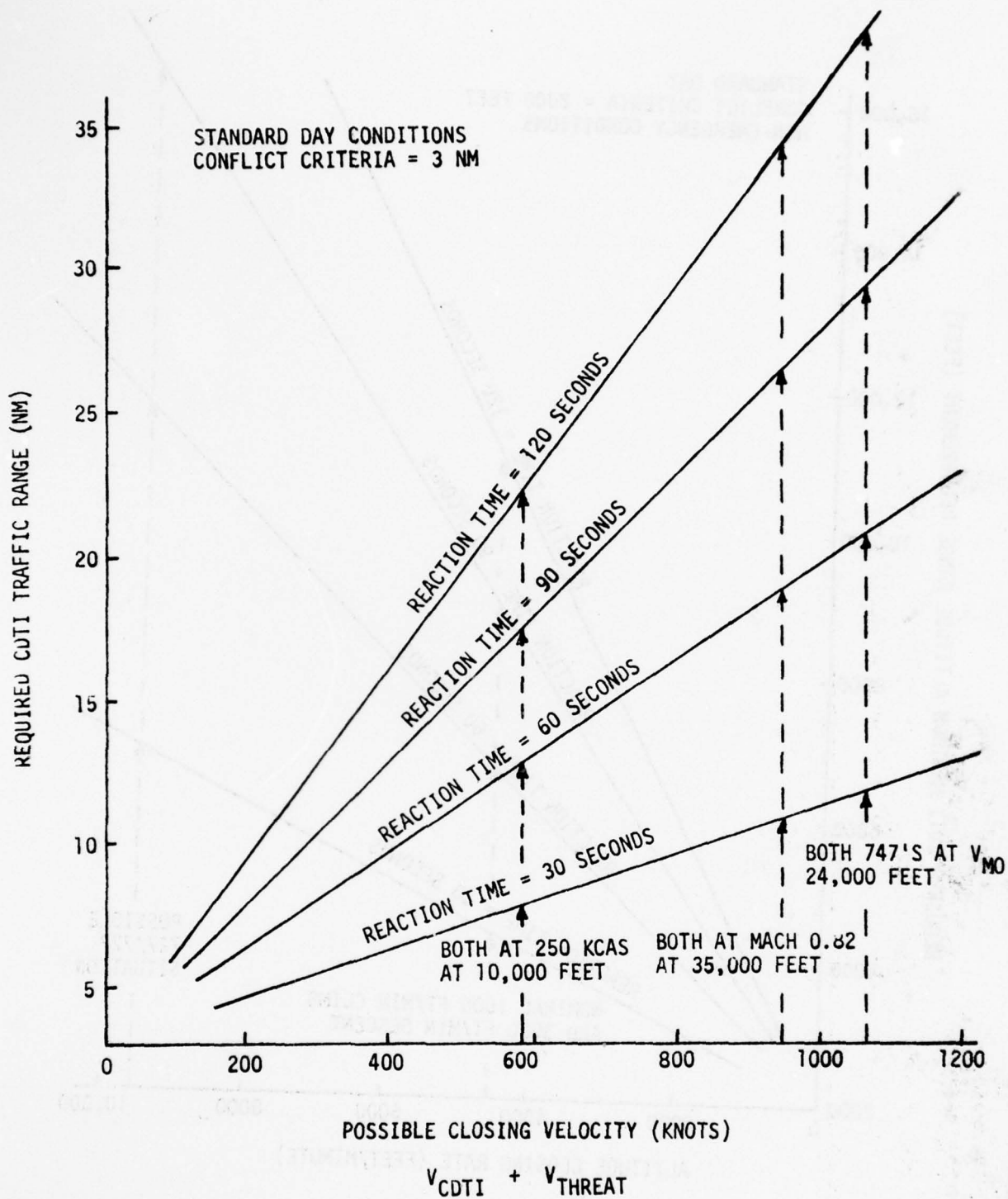


FIGURE 4.1.1- 1 HORIZONTAL CDTI TRAFFIC RANGE

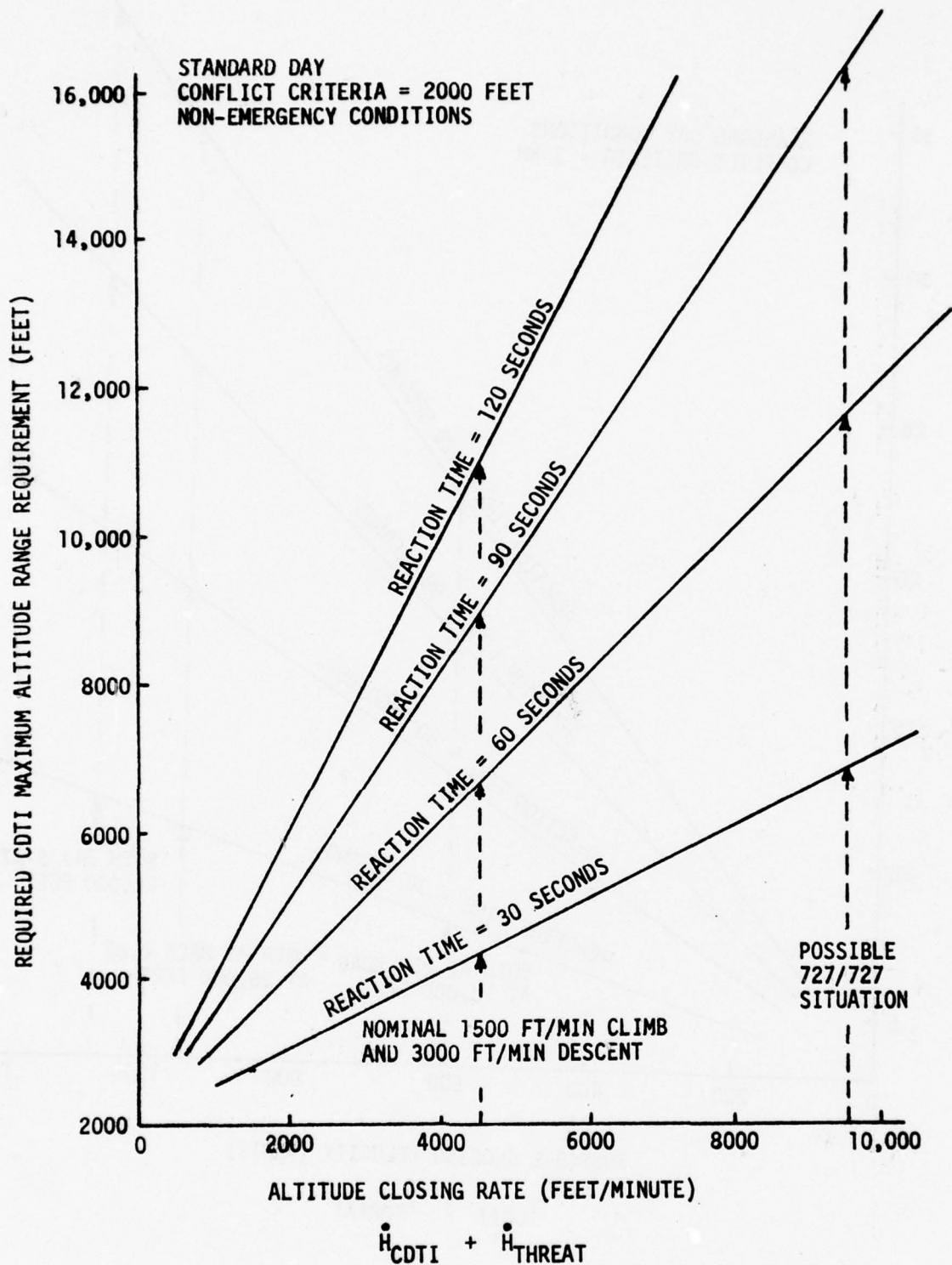


FIGURE 4.1.1 - 2 VERTICAL CDTI TRAFFIC RANGE

4.1.1.4 Operational Concept

The following operational concept is recommended based on consideration of the general TMA operations monitor role and available data.

4.1.1.4.1 Assumptions

The operational concept is based on the following assumptions:

- 1) ATC will provide IFR separation and TCA VFR/IFR separation.
- 2) IPC will be the primary system for evaluating the collision threat.
- 3) One or more airplanes can be CDTI equipped.
- 4) The CDTI airplane does not initiate maneuvers based on CDTI data.
- 5) The CDTI display will contain relative position of all traffic in the proximity of the CDTI aircraft.

4.1.1.4.2 Generalized Concept

The following general concept for the potential application of CDTI to the general TMA operations monitor role is proposed. The CDTI aircraft will have a display of surrounding traffic on the EHSI. Traffic will be displayed as relative position and bearing from the CDTI airplane with identification and differential altitude information. Heavy airplanes requiring additional separation for wake turbulence will be identified.

ATC will control traffic as necessary to assure safe and efficient flow. The CDTI pilot will monitor traffic on the CDTI to aid his understanding of the surrounding environment. He will monitor both to assure adequate separation and as an aid to visually acquiring traffic. If he discovers any abnormal or confusing situation, he will contact the controller for additional information

or resolution. The controller will resolve problems and provide information as requested. He will not provide radar traffic advisory service to CDTI-equipped aircraft.

4.1.1.4.3 Flow Diagram

Figure 4.1.1-3 illustrates the functional flow relationships for the CDTI general TMA operations role.

4.1.1.4.4 Application Areas

This role is generally applicable to all phases of flight in the terminal area.

4.1.1.4.5 Operating Procedures

No special operating procedures beyond those discussed already appear to be necessary.

4.1.1.5 System Requirements and Concept

The basic functional requirement is to provide the CDTI pilot with the display of surrounding traffic information sufficient for him to monitor his surrounding situation. The following paragraphs describe the performance requirements and display concept.

4.1.1.5.1 Performance Requirements

Assuming that the ability to perform the monitoring will be based on a display of relative position of surrounding traffic, the following system performance parameters are estimated.

Number of Targets - Further testing is needed to determine which targets and how many targets a pilot will examine. This can define the maximum number

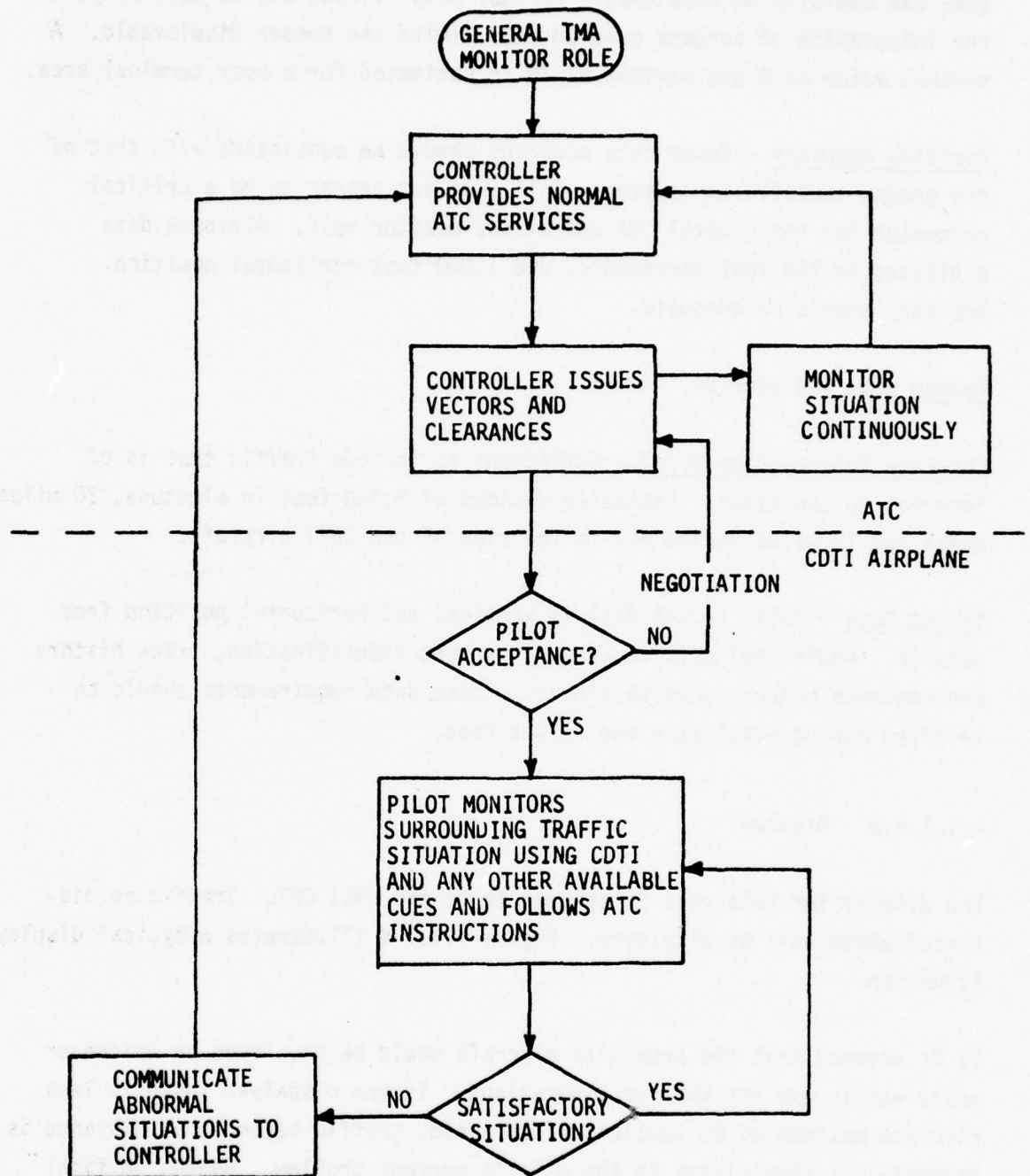


FIGURE 4.1.1 - 3 CDTI GENERAL TMA OPERATIONS MONITOR ROLE

that can usefully be displayed. Further prioritizing may be necessary, if the integration of targets onto an EHSI limits the number displayable. A nominal value of 6 and maximum of 20 is estimated for a busy terminal area.

Position Accuracy - Input data accuracy should be consistent with that of the ground surveillance system. This does not appear to be a critical parameter for the general TMA operations monitor role. Altitude data digitized in 100 foot increments, and 1,000 foot horizontal position accuracy should be adequate.

Update Rate - 4 seconds.

Coverage Volume (Displayed) - Sufficient to include traffic that is of interest to the pilot. Estimated maximum of 5,000 feet in altitude, 20 miles ahead and 10 miles behind and to the side of the CDTI aircraft.

Target Data - Basic target data is vertical and horizontal position from ownship. Additional data required is target identification, track history and sequence numbers when pertinent. These data requirements should be verified during simulation and flight test.

4.1.1.5.2 Display

The display for this role is assumed to be the EHSI CRT. Traffic as discussed above will be displayed. Figure 4.1.1-4 illustrates a typical display situation.

It is assumed that the proximate aircraft would be displayed on whichever scale was in use for EHSI considerations. If the displayed range is less than the maximum of 20 nautical miles ahead, traffic beyond that distance is probably not significant to the pilot's current problem. Hence, on final a 10 mile display range is adequate since he has no interest in a departure beyond 10 miles, but is very interested in the airplane ahead or to the side on arrival paths.

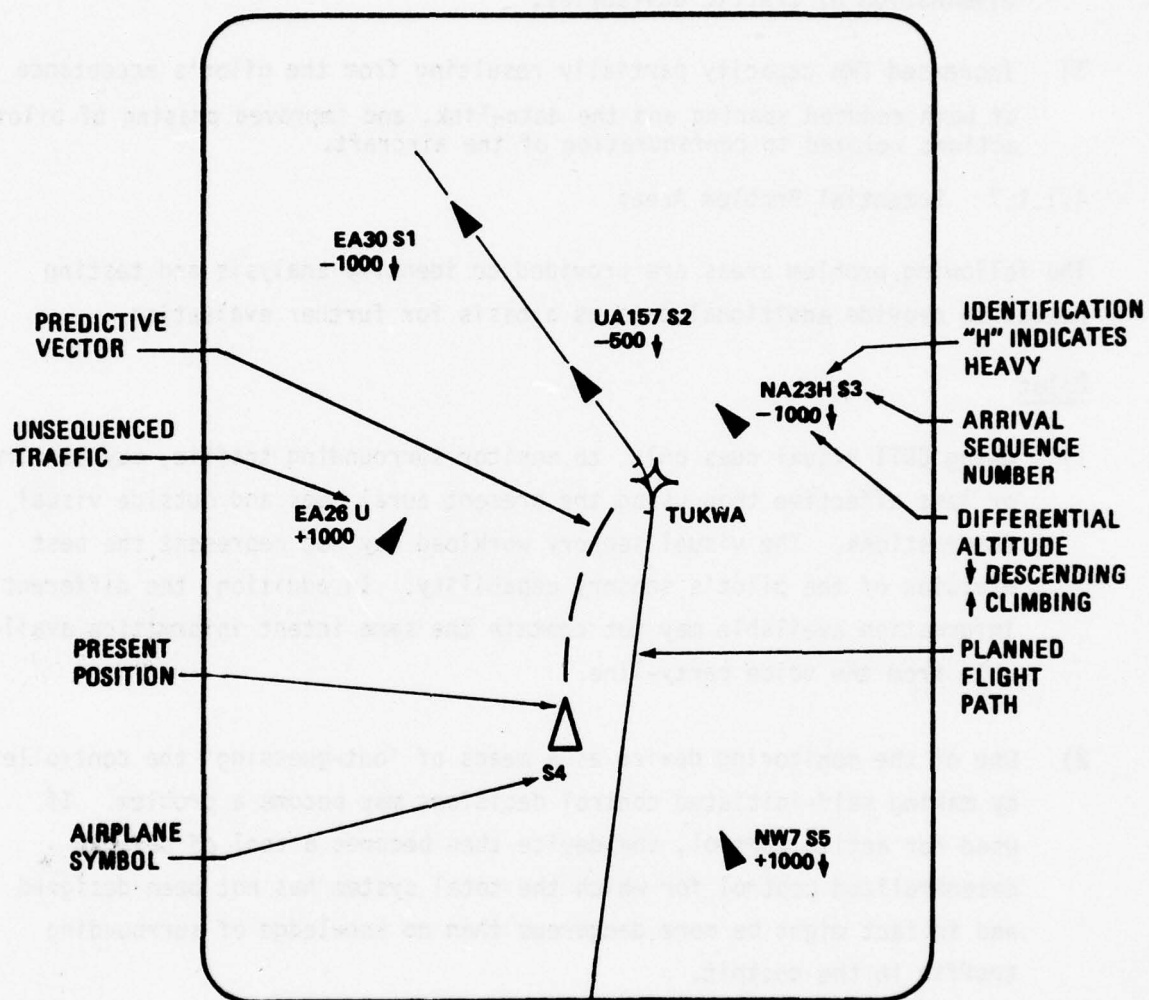


FIGURE 4.1.1-4 TYPICAL CDTI GENERAL TMA OPERATIONS MONITOR

4.1.1.6 Potential Benefits

The potential benefits of the CDTI general TMA monitoring role are:

- 1) Improved system safety from having a pilot who is better informed as to his operational environment and the controller's traffic limitations;
- 2) Reduced controller workload and communication associated through elimination of traffic advisories;
- 3) Increased TMA capacity partially resulting from the pilot's acceptance of both reduced spacing and the data-link, and improved phasing of pilot's actions related to configuration of the aircraft.

4.1.1.7 Potential Problem Areas

The following problem areas are provided to identify analysis and testing needed to provide additional data as a basis for further evaluation.

Pilot

- 1) Using CDTI visual cues only, to monitor surrounding traffic, may be more or less effective than using the present aural cues and outside visual observations. The visual sensory workload may not represent the best division of the pilot's sensory capability. In addition, the different information available may not contain the same intent information available from the voice party-line.
- 2) Use of the monitoring device as a means of "out-guessing" the controller by making self-initiated control decisions may become a problem. If used for active control, the device then becomes a tool of defacto decentralized control for which the total system has not been designed and in fact might be more dangerous than no knowledge of surrounding traffic in the cockpit.
- 3) The knowledge of all the aircraft in the vicinity may increase cockpit stress. Since the pilot does not necessarily know today what the traffic around him really looks like (particularly in IMC), the new knowledge may only increase stress.

- 4) A potential exists for the CDTI display to cause a significant distraction from the primary flight tasks or increase crew workload in a fashion not offset by workload benefits.

Operational

- 1) A net increase in controller or communication workload may be caused by pilot queries on situations the controller is already managing. This potential problem is essentially the question of "false alarm" rate.
- 2) The controller's ability adequately to keep straight which airplanes are being provided radar traffic advisory service and which are accomplishing monitoring with CDTI may be an area of confusion.
- 3) Assuming that clearances to aircraft would be delivered via the data-link rather than the party-line voice channel, it appears that some intent information about the other traffic is lost.

Design

The best methods of displaying and using relative traffic information for this monitoring role must be developed.

Performance

The CDTI display may not provide an adequate monitoring capability for surrounding traffic.

4.1.1.8 Test Scenario Considerations

Considerations for designing test scenarios for simulation and flight test include the following:

- 1) This role should be evaluated in all phases of terminal area operation

(e.g., IAF merging, M&S, vectoring, in-trail arrivals, departure, arrival interaction with departures, final approach, close proximity to traffic to or from other airports, etc.). The test scenarios should include both considerable surrounding traffic pressure and sparse traffic situations.

- 2) The scenario should provide for inclusion of a realistic busy mix of IFR and VFR traffic.
- 3) Intentional blunders or airspace conflicts should randomly occur at infrequent intervals to test pilot's ability to discover problems.
- 4) Both pilot and controller workload should be heavy and realistic to prevent total concentration on the CDTI role.
- 5) The analysis, simulation, and flight tests should be designed to address the identified potential problem areas and provide a definition of the boundary limitations for CDTI usefulness for this role.

4.1.2 Longitudinal Separation of Arrivals

This role is to use CDTI as a monitor for longitudinal separation during arrival operations.

4.1.2.1 Problem Statement

During arrival operations, when ATC has aircraft closed spaced in trail, the pilot would like assurance that the longitudinal separation has not gone below the safe minimum value. This will become more critical if in the future the longitudinal spacing minimums are reduced below today's values.

4.1.2.2 Solution Approach

The general solution to the longitudinal separation assurance problem is to provide the pilot with a CDTI display showing the aircraft ahead on the flight path to allow monitoring of the separation at any point in the approach. Should the CDTI pilot conclude that adequate separation may be lost or does not exist, he will contact the controller and request clarification and/or resolution.

4.1.2.3 Discussion

Acceptable separation to a pilot is related to his comprehension of the threat and his faith in the system providing that separation. This role proposes giving the pilot a graphic display of his spacing to the aircraft ahead on the flight path. In VFR conditions, pilots demonstrate confidence in closer spacings than are used under instrument conditions. The CDTI monitor may provide the pilot confidence to accept a reduction in minimum separations should other system elements and wake turbulence considerations support such a reduction. Even without reducing separations, the CDTI can increase pilot confidence by allowing the monitoring of separation as a backup to the controller.

4.1.2.4 Operational Concept

The following operational concept is recommended based on consideration of the arrival longitudinal separation monitor role and available data:

4.1.2.4.1 Assumptions

- 1) ATC will provide in-trail spacing.
- 2) One or more airplanes can be CDTI-equipped.
- 3) The CDTI pilot does not initiate maneuvers based on CDTI data, but rather contacts the controller.
- 4) The display will contain relative position of the traffic ahead on the track if within a specified monitor distance.

4.1.2.4.2 Generalized Concept

The following general concept for the application of CDTI to the arrival longitudinal separation monitor role is proposed. The CDTI aircraft will have a display of the airplane ahead on the flight path. The target airplane's range, bearing, identification, and differential altitude will be shown. Heavy airplanes requiring additional separation for wake turbulence will be identified.

ATC will control traffic as necessary to assure adequate in-trail spacing. The CDTI pilot will monitor the target traffic on the CDTI to observe that adequate longitudinal separation is maintained. If the separation is becoming inadequate, he will immediately contact the controller and notify him of the situation. The controller is then responsible for issuing any necessary instructions to resolve the situation.

4.1.2.4.3 Flow Diagram

Figure 4.1.2-1 illustrates the functional flow relationships for the arrival longitudinal separation monitor role.

4.1.2.4.4 Application Areas

This role is applicable to those terminal arrival situations where airplanes are being controlled in-trail at spacings near minimum separations. The most common situation would be the final approach course situation where the airplanes are densely packed in-trail. The in-trail situation can also exist at other points in the terminal arrival geometry. Where M&S achieves control by airspace vectoring, most in-trail situations will occur in the later stages of approach. In situations where long in-trail streams feed from en route to the runway, this technique could be used for monitoring longitudinal separation during the entire TMA transition.

4.1.2.4.5 Operating Procedures

No special operating procedures beyond those already discussed appear to be necessary.

4.1.2.5 System Requirements and Concept

The basic functional requirement is to provide the CDTI pilot with a display of the arrival airplane ahead to allow monitoring of separation distance. The following paragraphs describe the performance requirements and display concept.

4.1.2.5.1 Performance Requirements

Assuming that the ability to perform the monitoring will be based on the display of the relative position of the aircraft ahead, the following system performance parameters are estimated:

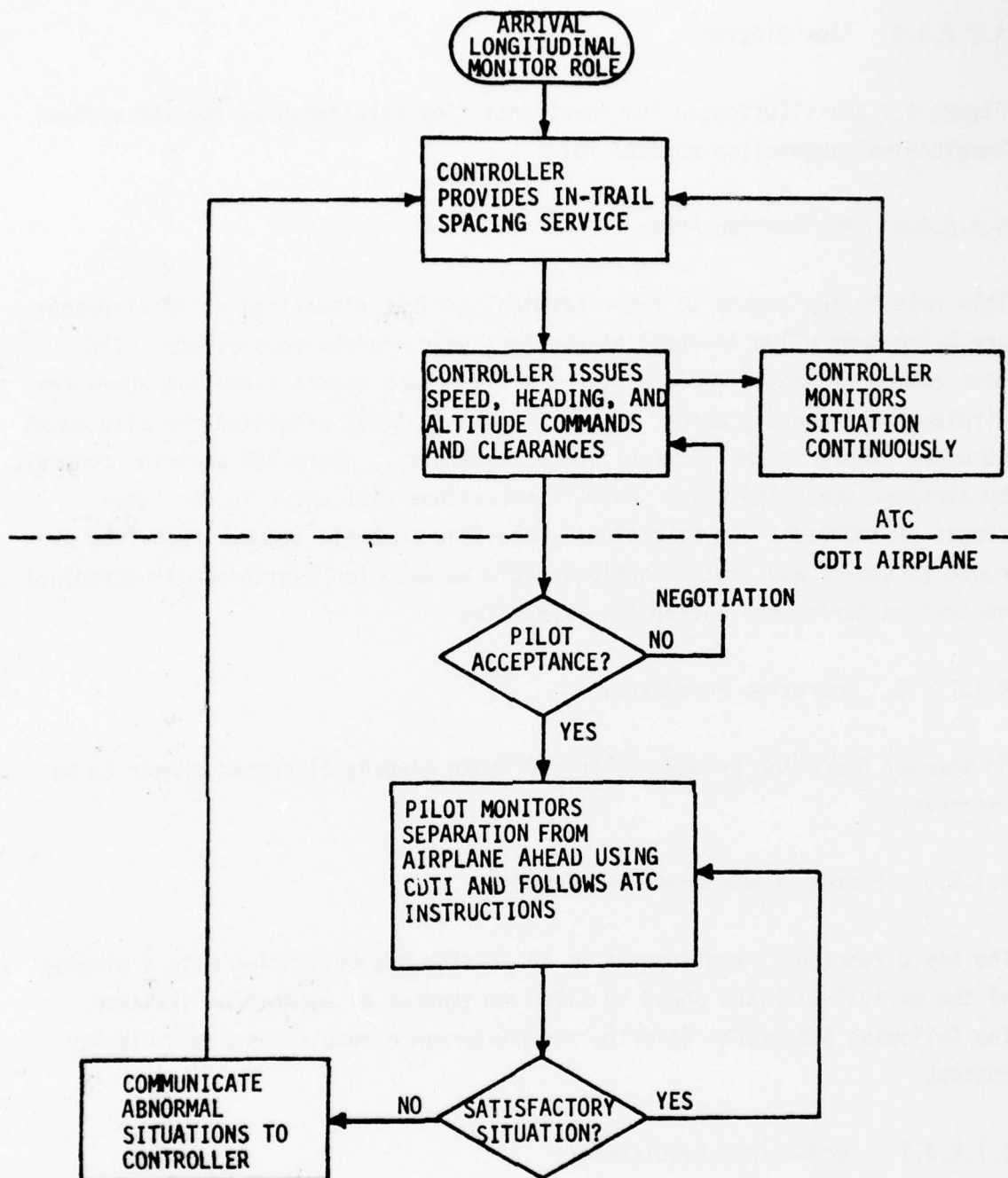


FIGURE 4.1.2 - 1 CDTI ARRIVAL LONGITUDINAL SPACING MONITOR ROLE

Number of Targets - One.

Position Accuracy - Altitude data digitized in 100 foot increments and 1,000 feet horizontal position accuracy will be compatible with ATC data sources.

Update Rate - 4 seconds.

Coverage Volume (Displayed) - Sufficient to include the airplane ahead when near minimum separation. A forward range of 7 nautical miles and 3 miles to either side of the approach path is adequate.

Target Data - Basic target data is vertical and horizontal position relative to ownship. Additional data required is target identification, an indication of the minimum separation distance, and data indicating closing rate (e.g., relative ground speed).

4.1.2.5.2 Display

The display for this role is assumed to be the EHSI CRT with target traffic displayed. Figure 4.1.2-2 illustrates a typical display situation for this role.

It is assumed that the desired approach track is an EHSI function. Should this not be the case, it would likely need to be added for this role to provide a frame of reference for the relative traffic separation situation.

The target airplane would be displayed on whichever scale was in use for EHSI purposes. However, the procedure for EHSI scale selection should assure that the scale is satisfactory for monitoring.

4.1.2.6 Potential Benefits

The potential benefits of the CDTI arrival longitudinal separation monitor

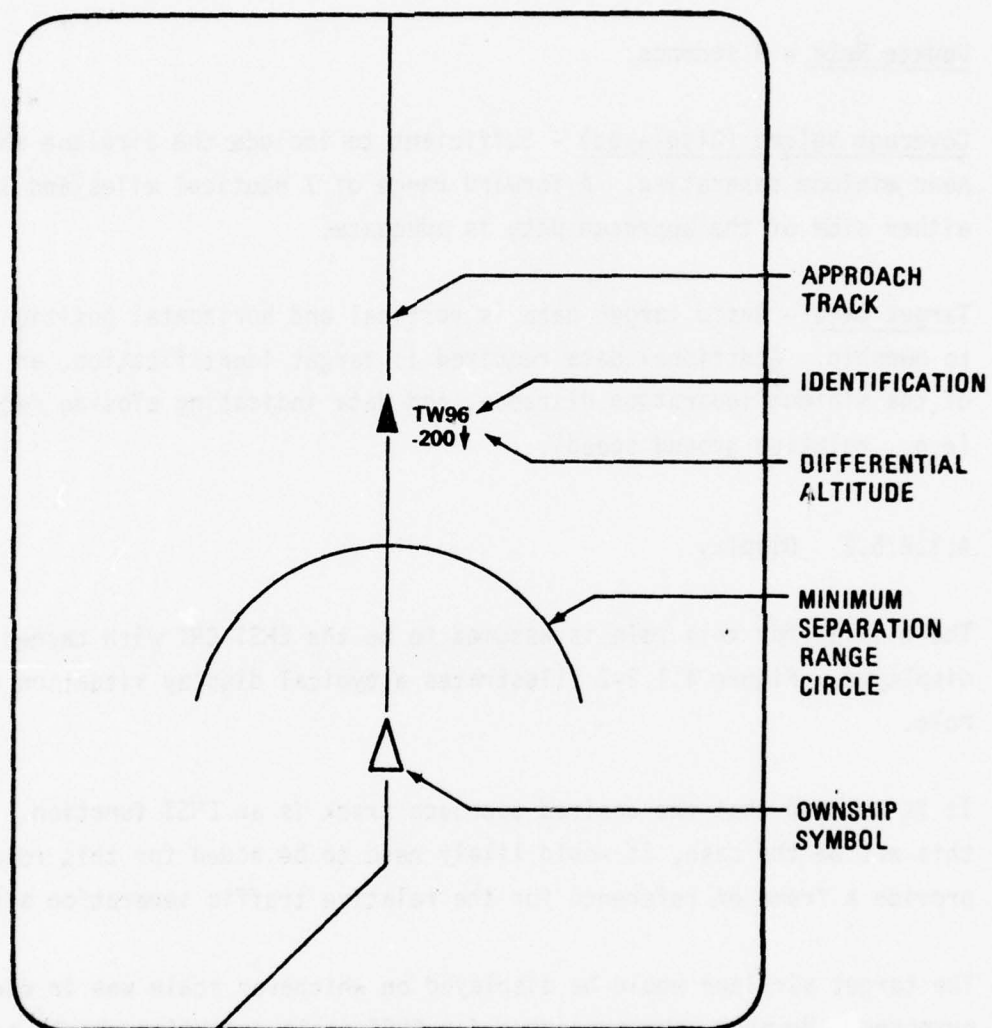


FIGURE 4.1.2-2 CDTI ARRIVAL LONGITUDINAL SPACING MONITOR ROLE

role are:

- 1) Improved system safety with a better informed pilot with respect to his spacing from the airplane ahead on the arrival path.
- 2) Increased TMA capacity from the pilot's acceptance of reduced arrival separation minimums. There have been indications from pilots and pilots' groups that without some cockpit monitor of this type, they would be reluctant to fly closer separations which technically might be allowed by improvements in other ATC elements. This benefit would be shared with those ATC elements.

4.1.2.7 Potential Problem Areas

The following problem areas are provided to identify analysis and testing needed to provide additional data as a basis for further evaluation.

Pilot

This role has the same potential problems as the general TMA role: (1) the visual vs. aural cues; (2) potential workload increase; and (3) pilot initiated control actions. This role also has the possibility that if the target airplane strays (intentionally or accidentally) from the approach course, the CDTI airplane may err by following.

Operational

This role also has the false alarm rate problem and loss of intent information of the general TMA role.

Design

The best methods of displaying and using relative traffic information for this monitoring role must be developed.

Performance

The CDTI display may not provide an adequate monitoring capability for in-trail separation.

4.1.2.8 Test Scenario Considerations

Considerations for designing test scenarios for simulation and flight test include the following:

- 1) This role should be evaluated in all phases of terminal area operation where aircraft are controlled in-trail.
- 2) Intentional blunders causing loss of separation should randomly occur on infrequent intervals to test pilot's ability to discover problems.
- 3) Both pilot and controller workload should be heavy and realistic to prevent total concentration on the CDTI role.
- 4) The analysis, simulation, and flight tests should be designed to address the identified potential problem areas and provide a definition of the boundary limitations for CDTI usefulness for this role.

4.1.3 Independent Parallel Approaches

This is the CDTI role in which pilot assurance of separation from traffic on the parallel path during independent simultaneous approaches to parallel runways is provided by monitoring that traffic on the CDTI.

4.1.3.1 Problem Statement

A significant increase in airport capacity under IFR operating conditions will result at a number of airports if independent ILS approaches are permitted on closely spaced parallel runways. The present rule stipulates a minimum 4300 foot spacing between centerlines for independent operations. The minimum was reduced in 1975 from 5000 feet and allows parallel independent operations under IFR conditions at Atlanta International as well as Chicago O'Hare and Los Angeles International. For parallel runway airports with separations less than 4300 feet, the appropriate longitudinal separation rules must be applied to arrivals on alternate approaches, or operate one runway for arrivals and the other for departures. Factors involved in the 4300 foot separation requirement include terminal navigational accuracies, aircraft dynamic characteristics, ILS geometry, final approach procedures, and ATC performance characteristics--surveillance accuracies and response times.

The DOT Air Traffic Control Advisory Committee recommended in 1969 (Reference 3) "Additional capacity can be provided by utilizing airport acreage more efficiently by decreasing the 5000 foot separation between independent IFR runways. The committee believes it will be possible to safely reduce this separation between runways to 2500 feet." Subsequently, in 1975, the parallel approach centerline minimum was decreased to 4300 feet. Numerous studies have cited performance requirements and altered procedures to support further reduction of the separation minimum.

Results of one Boeing study (Reference 4) on requirements to reduce parallel runway separations are illustrated in Figures 4.1.3-1 and 4.1.3-2. The first

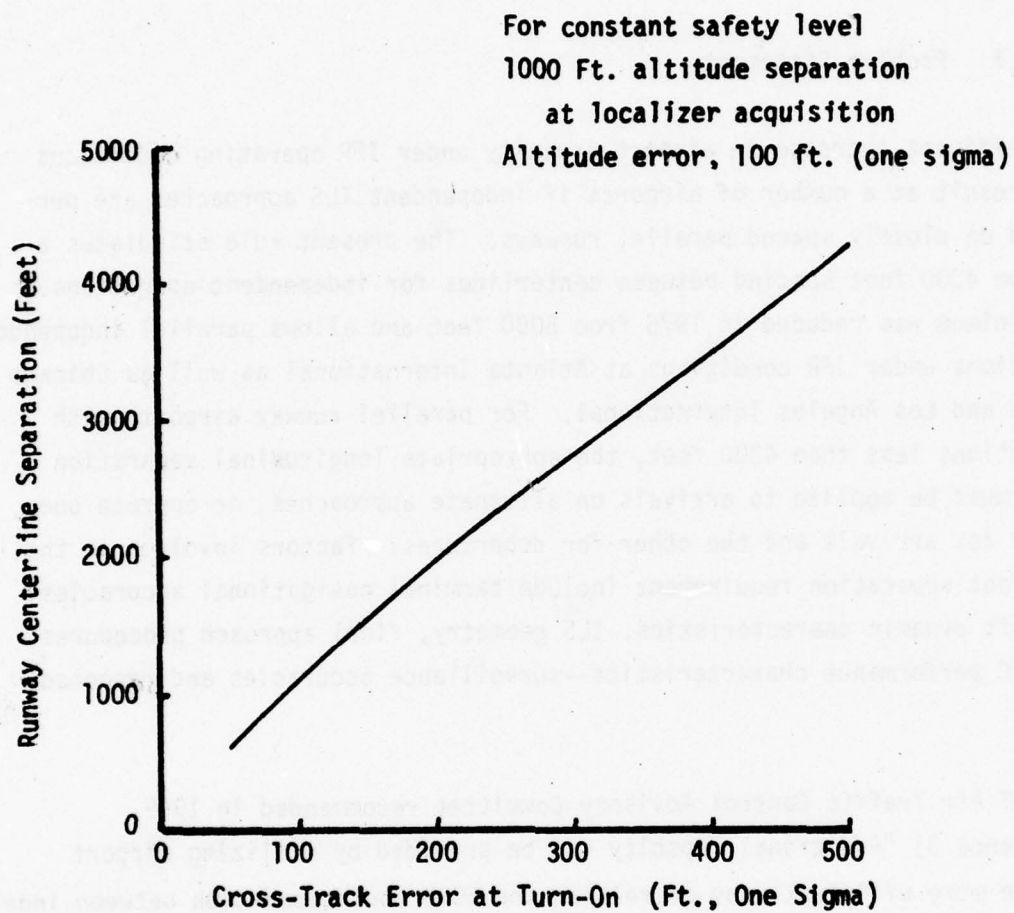


FIGURE 4.1.3-1

NAVIGATION REQUIREMENTS

Assumes Constant Safety Level

4 milliradian azimuth accuracy

Mean communications/control response time:

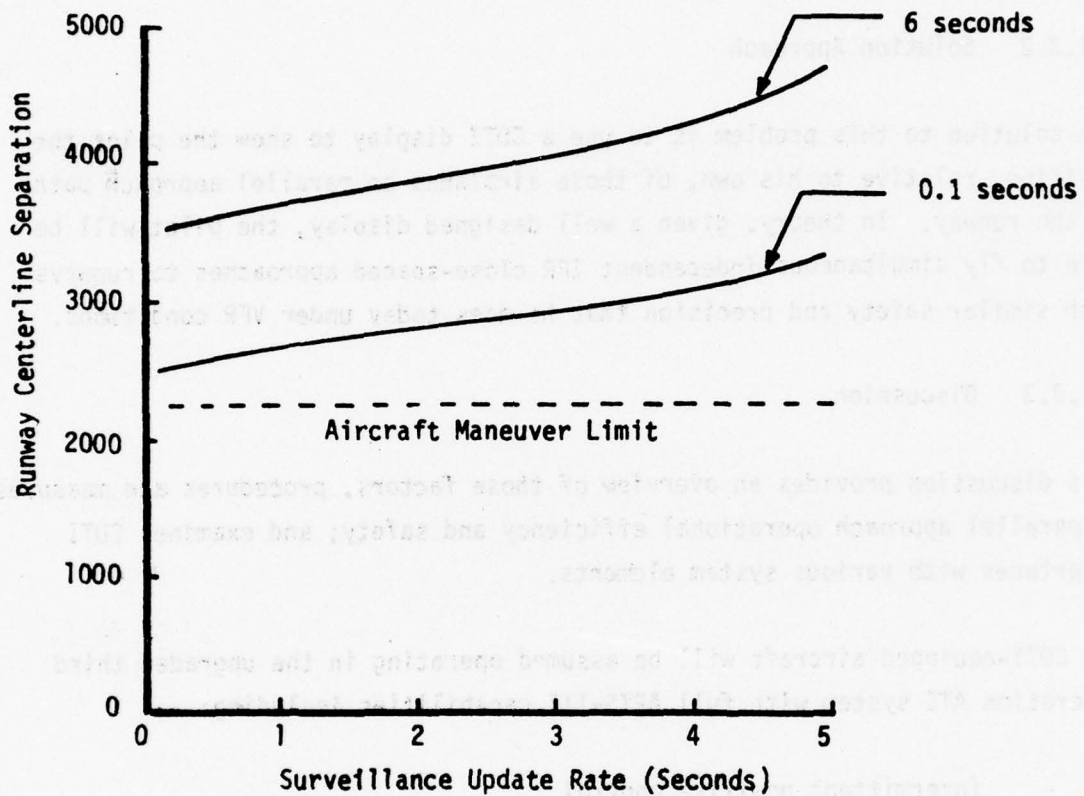


FIGURE 4.1.3-2

COMMUNICATIONS/SURVEILLANCE REQUIREMENTS

figure summarizes navigation/guidance requirements and the second communications/surveillance requirements. These results show that the communications/control response time becomes the critical factor in reducing separation below 3000 feet.

The problem is how to use the CDTI to provide assurance to pilots that safe lateral separation exists during parallel approaches.

4.1.3.2 Solution Approach

The solution to this problem is to use a CDTI display to show the pilot the position, relative to his own, of those airplanes on parallel approach paths to the runway. In theory, given a well designed display, the pilot will be able to fly simultaneous independent IFR close-spaced approaches to runways with similar safety and precision that he does today under VFR conditions.

4.1.3.3 Discussion

This discussion provides an overview of those factors, procedures and measures of parallel approach operational efficiency and safety; and examines CDTI interfaces with various system elements.

The CDTI-equipped aircraft will be assumed operating in the upgraded third generation ATC system with full ARTS-III capabilities including:

- intermittent positive control
- DABS with data-link
- voice communications, pilot to controller
- microwave landing system.

It is within the operation and capabilities of these systems that the concept will be mechanized and operated.

Figure 4.1.3-3 summarizes the various system elements, operational considerations

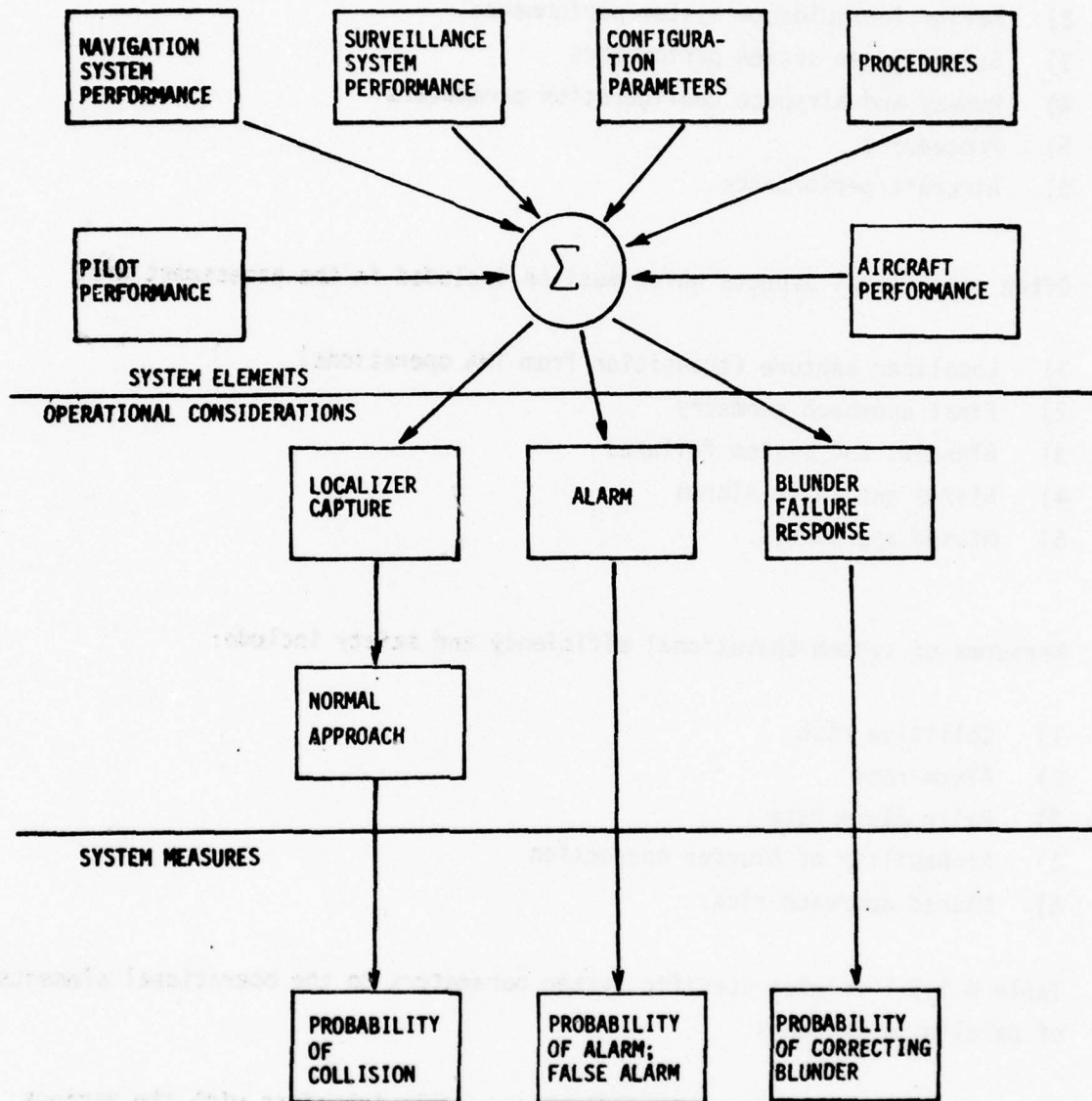


FIGURE 4.1.3-3
PARALLEL APPROACH OPERATIONS ASSESSMENT

and system measures involved in the assessment of operational efficiency and safety of parallel approach operations. Factors which impact parallel approach operations include:

- 1) Pilot/autopilot performance
- 2) Navigation/guidance system performance
- 3) Surveillance system performance
- 4) Runway and airspace configuration parameters
- 5) Procedures
- 6) Aircraft performance.

Often operational aspects which must be included in the assessment are:

- 1) Localizer capture (transition from TMA operations)
- 2) Final approach geometry
- 3) Blunders and system failures
- 4) Alarms and false alarms
- 5) Missed approaches.

Measures of system operational efficiency and safety include:

- 1) Collision risk
- 2) Alarm rate
- 3) False alarm rate
- 4) Probability of blunder correction
- 5) Missed approach risk.

Table 4.1.3-1 relates specific system parameters to the operational elements of parallel approaches.

Figure 4.1.3-4 summarizes the CDTI monitor role interface with the various elements of the parallel approach operating environment.

TABLE 4.1.3 - 1 PARAMETERS IMPACTING PARALLEL APPROACH OPERATIONS			
OPERATING CONSIDERATIONS:	NAVIGATION/SURVEILLANCE PERFORMANCE	CONFIGURATION/PROCEDURES DEFINITION	AIRCRAFT PARAMETERS
NORMAL APPROACH	CROSS TRACK NAVIGATION: DISTRIBUTION TYPE STANDARD DEVIATION ALTITUDE NAVIGATION: DISTRIBUTION TYPE STANDARD DEVIATION	RUNWAY CENTERLINE SEPARATION GLIDE SLOPE ELEVATION ANGLES TURN-ON LOCALIZER ALT. FINAL APPROACH PATH LENGTH NOMINAL LONG. SEPARATION	PHYSICAL DIMENSIONS NOMINAL APPROACH VELOCITY SEPARATION LOSS RATES
ALARM	ATC/COMM/PILOT RESPONSE TIME SURVEILLANCE UPDATE RATE SURVEILLANCE AZIMUTH ACCURACY	NO TRANSGRESSION ZONE WIDTH DECISION LOGIC	APPROACH VELOCITY DIST. ROLL RATE BANK ANGLE DISTRIBUTION
FALSE ALARM	CROSS-TRACK NAV. DISTRIBUTION SURVEILLANCE AZIMUTH ACCURACY	NORMAL OPERATING ZONE WIDTH DECISION LOGIC	
TURN-ON	POSITION/HEADING ERRORS LOCALIZER BEAM WIDTH (CROSS-WIND COMPONENT) PILOT RESPONSE TIME	INTERCEPT ANGLE	APPROACH VELOCITY DIST. ROLL RATE LIMITING BANK ANGLE

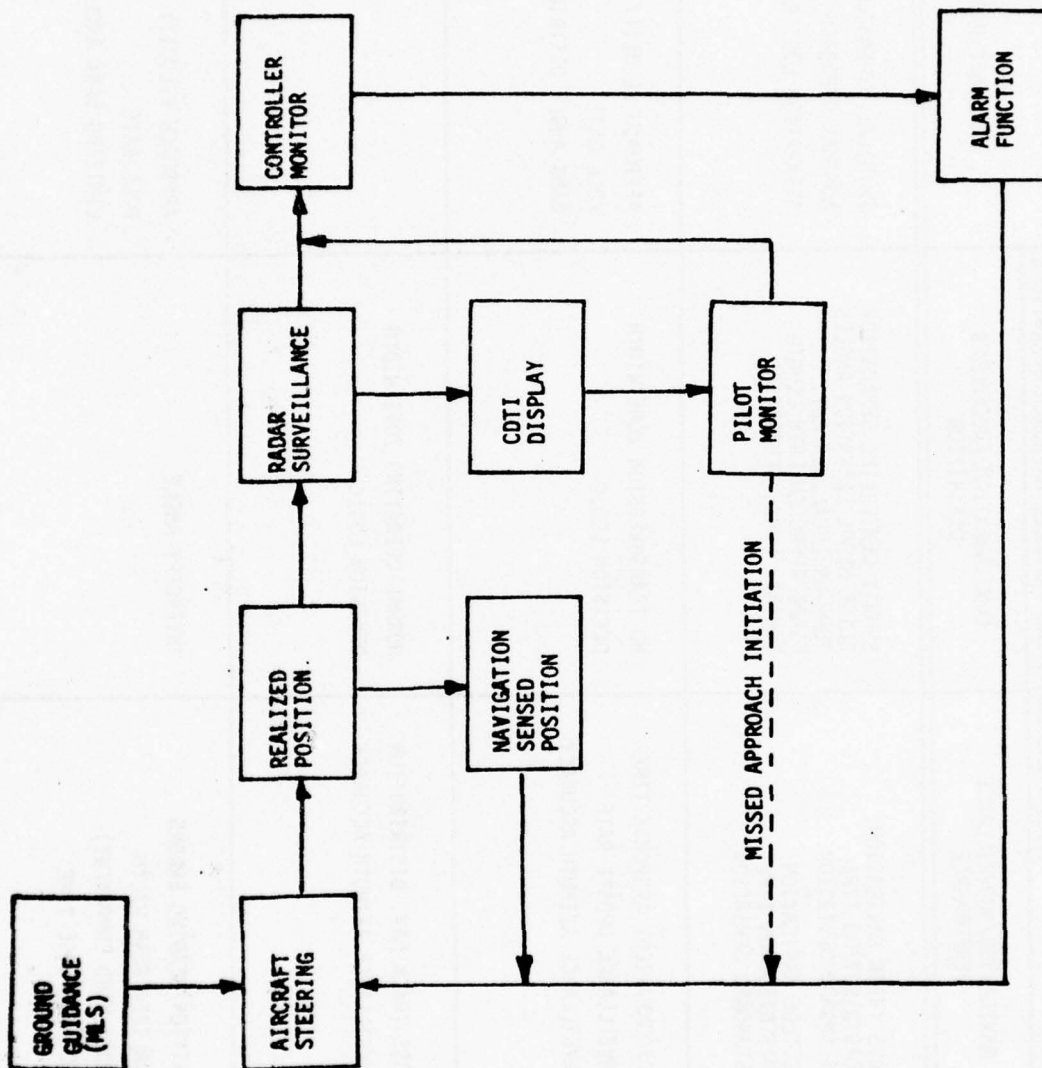


FIGURE 4.1.3-4 CDTI INTERFACES

4.1.3.4 Operational Concept

The following is the recommended operating concept for the parallel approach monitoring role.

4.1.3.4.1 Assumptions

The operational concept is based on the following assumptions:

- 1) CDTI will not be employed in a navigation/guidance or CAS role due to performance and operational considerations.
- 2) Primary navigation/guidance on final approach will be provided by MLS.
- 3) Blunder/failure surveillance will be performed - as now - by the ground system; the pilot with CDTI can provide a backup surveillance function.
- 4) Blunder/failure surveillance will probably be the limiting safety element in achieving close-spaced parallel runway operations (perhaps down to 2500 feet).
- 5) The pilot may use CDTI to initiate a missed approach on final approach to a close-spaced parallel runway if the situation warrants the maneuver.

4.1.3.4.2 Generalized Concept

The following general concept is proposed for potential application of CDTI-equipped airplanes to the parallel approach monitor role. The pilot will use CDTI on parallel approach to:

- 1) Monitor aircraft on the alternate approach;

- 2) Assess impending conflicts and notify ATC; and
- 3) Initiate a missed approach if
 - a) CDTI information indicates a conflict situation developing,
 - b) the pilot assesses inadequate time exists to notify ATC and correct the situation; and
 - c) the pilot assesses that the missed approach trajectory will decrease conflict likelihood.

4.1.3.4.3 Flow Diagram

Figure 4.1.3-5 typifies the decision process and logic which might be employed by the pilot in utilizing the CDTI to perform the final approach monitoring function to a close-spaced parallel runway.

4.1.3.4.4 Application Areas

CDTI parallel approach monitoring is applicable to all close-spaced instrument approaches to provide pilot assurance and acceptance. CDTI provides a backup blunder/failure monitor to the ground function. In addition, CDTI may allow an additional safety option (initiation of a missed approach) in situations where a blunder/failure has occurred, a conflict seems imminent, inadequate time exists to contact ATC, and the maneuver appears to enhance safety.

4.1.3.4.5 Operating Procedures

The concept involves six phases:

- 1) Monitoring of parallel runway traffic on a close-spaced approach.

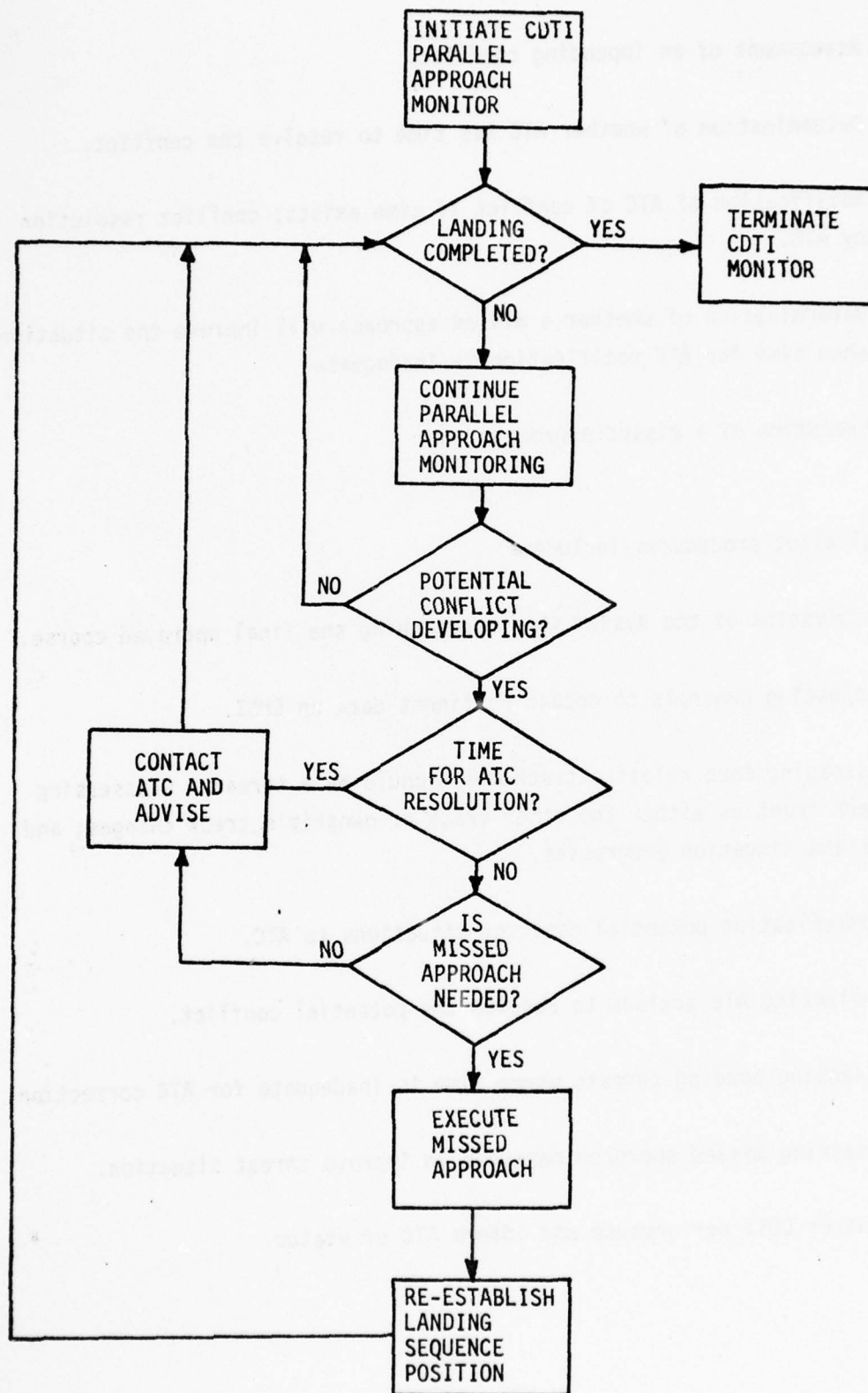


FIGURE 4.1.3 - 5 PARALLEL APPROACH MONITOR LOGIC

- 2) Assessment of an impending conflict.
- 3) Determination of whether ATC has time to resolve the conflict.
- 4) Notification of ATC of conflict if time exists; conflict resolution by ATC.
- 5) Determination of whether a missed approach will improve the situation when time for ATC notification is inadequate.
- 6) Execution of a missed approach.

General pilot procedures include:

- 1) Activation of the system when approaching the final approved course.
- 2) Adjusting controls to obtain pertinent data on EHSI.
- 3) Assessing each relative track which could be a threat. Reassessing each track as either the other track or ownship's track changes; and as the situation progresses.
- 4) Communicating potential conflict situations to ATC.
- 5) Evaluating ATC actions to resolve the potential conflict.
- 6) Assessing pending threats where time is inadequate for ATC correction.
- 7) Assessing missed approach maneuver to improve threat situation.
- 8) Monitor CDTI performance and inform ATC of status.

General ATC procedures include:

- 1) Activate each participating flight into the CDTI parallel approach surveillance operation as it enters the TMA.
- 2) Evaluate each reported potential conflict and determine required resolution action.
- 3) Transmit control instructions to resolve conflict.
- 4) Report conflict resolution action to pilot.

4.1.3.5 System Requirements and Concept

The following sections discuss the system performance requirements and display concept.

The basic functional requirements of the parallel approach monitor role for CDTI are to: (1) provide information on traffic on the parallel path; and (2) provide criteria showing safe final approach operating regions and situations.

4.1.3.5.1 Performance Requirements

Assuming that monitoring of final approach operations will be based on a display of adjacent approach traffic, the following are the estimated system performance requirements. These requirements assume that the CDTI data processing and display performance should be comparable to that of the ground-based system. These values require verification and refinement by simulation and test.

Number of Targets - Two closest aircraft on the parallel runway approach course.

Position Accuracy - A function of runway separation minimum. Ground system values estimated are:

4300 ft. separation	4.0 milliradian azimuth accuracy
3500 ft. separation	3.0 milliradian azimuth accuracy
3000 ft. separation	3.0 milliradian azimuth accuracy
2500 ft. separation	2.5 milliradian azimuth accuracy.

Surveillance Update Rate - A function of runway separation minimum. Ground systems values estimated are:

4300 ft. separation	4 seconds update
3500 ft. separation	2 seconds update
3000 ft. separation	1 second update
2500 ft. separation	1 second update.

Communications/Control Response Time - A function of runway separation minimum. Ground system values estimated are:

4300 ft. separation	6.0 seconds (expected value)
3500 ft. separation	4.0 seconds (expected value)
3000 ft. separation	2.0 seconds (expected value)
2500 ft. separation	0.1 second (expected value).

Covered Volume (Displayed) - 2000 feet in altitude, 5 miles laterally and 10 miles longitudinally from ownship position.

Target Data - Basic target data is vertical and horizontal position. Additional data required, either supplied or derived onboard, are turn rate and velocity vector.

4.1.3.5.2 Displays

The display presents the target data and additional situation information. The choice of system mechanization has direct implications on the data available for display.

The desirable situation data are indications of:

- 1) Nominal approach paths to both runways,
- 2) No transgression zone boundaries,
- 3) Runway locations.

The desirable target data includes:

- 1) Present position of ownship and other aircraft
- 2) Differential altitude of other aircraft relative to ownship
- 3) Projected position of ownship and other aircraft
- 4) Projected time to conflict or collision.

It is also possible that some additional missed approach initiation information could be mechanized providing the pilot with a quick assessment of the desirability of initiating a missed approach given a dangerous blunder/failure situation.

4.1.3.6 Potential Benefits

The potential benefits of CDTI parallel approach monitoring is to increase airport capacity by facilitating cockpit acceptance of reduced runway separation requirements for simultaneous independent parallel approaches.

4.1.3.7 Potential Problem Areas

The following problem areas are associated with the application of CDTI to parallel approach monitoring. These areas indicate analysis and testing needed

to provide additional data to further evaluate the proposed CDTI use. The problem areas are divided into pilot, operational, design, and performance considerations.

Pilot

- 1) The increase in pilot workload and possible diversion of pilot's attention from critical flight instruments due to the CDTI guidance requirements may be a problem. A justification on the basis of safety given the infrequency of blunders or failures must be made.
- 2) The likelihood of decreased safety due to initiation of unnecessary (false alarm) missed approaches is possible.
- 3) The pilot may use the data as the basis for taking avoidance action without ATC approval. The content and accuracy of CDTI information may be inadequate to support this action. Such actions may result in disruption of the orderly flow of traffic and possibly the production of unsafe situations where none originally existed.

Operational

- 1) If the information is inadequate, the pilots may be unnecessarily querying ATC relative to the situation, producing a high workload in the cockpit, over the voice communication link and in the ATC control facility.
- 2) In the event of a blunder or failure, a pilot-initiated conflict alarm may impede ATC reaction time (assuming they are already cognizant of the situation).

Design

The best (or an adequate) method of displaying and using relative position

traffic data to fly final approaches must be developed. Solutions developed with an onboard area navigation system will be different from those developed without such a capability.

Performance

A CDTI-equipped airplane may not be able to determine a missed approach maneuver accurately and within the required time interval.

4.1.3.8 Test Scenario Considerations

Considerations in designing scenarios for simulation or flight tests include the following:

- 1) Final approach traffic for investigating ATC operational problems should assume a high-density structure with airline guide or actual observed traffic demand and aircraft type sequence.
- 2) The scenario should be complete for both pilot and controller workload; accounting for all tasks and actions the operators are loaded with while doing their basic job.
- 3) The scenario should include maximum workload situations for both pilot and controller.
- 4) Rare event occurrences should be programmed to investigate CDTI response and system recovery as to performance and safety.
- 5) Simulation should include the effects of IFR approaches in turbulence considering lateral deviations of parallel traffic and CDTI airplane response to turbulence.

4.1.4 Runway Occupancy Monitor

This role is to use CDTI as a monitor to assure that an assigned active runway is not occupied by another airplane.

4.1.4.1 Problem Statement

Accidents have resulted from situations where more than one airplane was attempting to use the same runway at the same time. Both the tower and pilot monitor runway occupancy when visual conditions are adequate. However, under conditions of limited visibility, the pilot cannot visually check that the runway is clear. Therefore, a means is desired in the cockpit to allow the pilot to monitor that the runway he intends to use is clear and can be expected to remain clear until he has completed his operation.

4.1.4.2 Solution Approach

The general solution for the CDTI runway occupancy monitor role is to provide a CDTI display of pertinent runway, taxi-way, and final approach course traffic which occupies (or could occupy) the runway assigned (or believed to be assigned) to the CDTI airplane. If an unsafe condition exists, the CDTI pilot contacts ATC for resolution.

4.1.4.3 Discussion

The runway occupancy monitor role initially appears simple as the basic question is "Is the runway occupied or isn't it?" However, more investigation quickly uncovers several more complex questions which impact the answer.

For introduction, consider that the tower controllers (i.e., both local and ground controllers) have accomplished their job in a correct and unambiguous fashion. The question now becomes one of whether all vehicle operators have a common comprehension of the situation. For example, an arrival on final approaches the wrong close-parallel and this runway contains a departure

awaiting takeoff clearance. A CDTI device would only be useful to the arrival if it contained traffic for other active runways in addition to the assigned runway.

Since runway operations are often dependent on close timing intervals, it may be that the combined intent of the controllers would be necessary to interpret the position situational display. For example, a taxiing aircraft may be asked to cross a runway which contains an in-place departure being held for other reasons (e.g., wake-turbulence separation time countdown). CDTI interpretation of such a situation may be difficult without the intent and may contribute to the "false alarm" workload.

A CDTI runway occupancy monitor must be capable of addressing the following situations:

CDTI-Equipped Arrival

- 1) Runway occupied by arrival ahead
- 2) Runway occupied by a departure
- 3) Runway occupied by taxiing aircraft
- 4) Runway occupied by airport vehicles
- 5) Crossing and adjacent active runways and their traffic must be shown.

CDTI-Equipped Departure

- 1) Display of final approach course to show arrivals on final for the departure's assigned runway
- 2) Runway occupied by taxiing aircraft
- 3) Runway occupied by previous arrival
- 4) Runway occupied by aborted takeoff ahead
- 5) Crossing active runways and their traffic as it effects the intersection
- 6) Runway occupied by airport vehicles.

CDTI-Equipped Taxiing Aircraft

- 1) Runway occupied, or about to be occupied, by an arrival or departing aircraft.
- 2) Runway occupied by other taxiing aircraft
- 3) Runway occupied by airport vehicles.

In addition, some means of indicating controller's intent or a positive indication of clearance priority might be a real asset as development of this role evolves.

Still another aspect of this role is the accuracy of the position data on all threats. Fifty feet can make a considerable difference in the interpretation of the situation. In addition, threats such as airport vehicles are not equipped for positive identification and location (e.g., with Beacon Transponders).

The surveillance accuracy implied by this role will require an update in surface surveillance capability. As improvement in this system is anticipated in the Upgraded Third Generation Airport Surface Traffic Control Phase II effort, the potential for this role exists in the future. Reference 5 indicates that the proposed Tower Automated Ground Surveillance (TAGS) system can provide an accuracy of 25 feet (one sigma) using beacon trilateration. This system would also have the digitizing capability required and could be combined with final approach target data via ARTS-III. The combined data would then be transmitted to the CDTI airplanes via DABS.

4.1.4.4 Operational Concept

The following operational concept is recommended based on consideration of the runway occupancy monitor role and available data:

4.1.4.4.1 Assumptions

- 1) The ATC system will have primary responsibility for scheduling all runway operations to assure they are conflict free.
- 2) One or more airplanes may be CDTI-equipped.
- 3) The CDTI airplane does not initiate maneuvers based on CDTI data, but contacts the controller for resolution of any questionable situation. The pilot, of course, has the prerogative of refusing a clearance or executing a missed approach based on all the information at his disposal.
- 4) The display will contain relative position of that traffic on, or about to use the active runways of interest.

4.1.4.4.2 Generalized Concept

The following general concept for the potential application of CDTI to the runway occupancy monitor role is proposed. The CDTI airplane will have a display of the traffic using or about to use the active runway and their relationship to the runway.

ATC will control traffic as necessary to assure non-conflicting use of the active runway(s). The CDTI pilot will monitor the traffic situation for any active runway he intends to use to assure no other airplane is occupying the runway. If he detects a conflict, or apparent conflict, he immediately contacts his controller for clarification or resolution. When taxiing traffic identifies an apparent conflict prior to entering the active runway, it shall not enter until the apparent problem has been resolved.

4.1.4.4.3 Flow Diagram

Figure 4.1.4-1 illustrates the functional flow for the CDTI runway occupancy role.

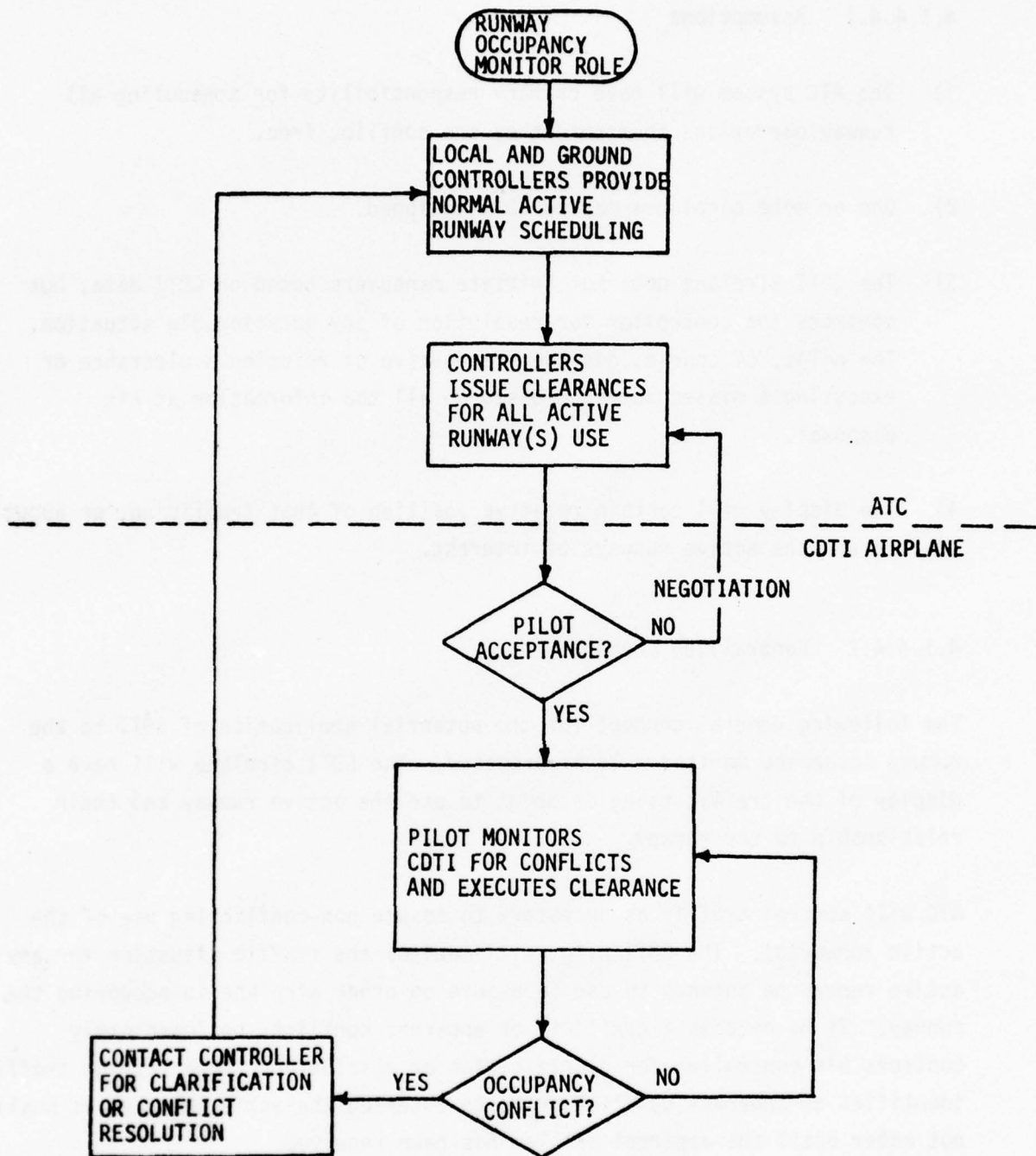


FIGURE 4.1.4 - 1 CDTI RUNWAY OCCUPANCY MONITOR ROLE

4.1.4.4.4 Application Areas

This role is applicable at any airport equipped to provide the required CDTI data.

4.1.4.4.5 Operating Procedures

No special operating procedures beyond those already discussed appear to be necessary.

4.1.4.5 System Requirements and Concept

The basic functional requirement is to provide the CDTI pilot a display of surface and final approach traffic which may conflict with his clearance to use an active runway. The following paragraphs discuss the performance requirements and display concept.

4.1.4.5.1 Performance Requirements

Assuming that the ability to perform the monitoring will be based on the display of relative traffic position, the following system performance parameters are estimated:

Number of Targets - Less than twelve.

Position Accuracy - Approximately 25 feet (one sigma). Altitude unnecessary.

Update Rate - 4 seconds.

Coverage Volume (Displayed) - Sufficient to include active runways and their final approach courses.

Target Data - Basic target data is horizontal position relative to ownship. Additional data required is aircraft identification. Targets are those airplanes which are occupying an active runway or are on the final approach course for the active runways of concern.

4.1.4.5.2 Display

The display for this role is assumed to be the EHSI CRT. A simple symbol such as an "X", to distinguish on the runway traffic from any other displayed traffic, is to be placed at its approximate location on the runway(s). The traffic, if it is moving, will be repositioned at each update cycle. Aircraft identification will be shown.

It is assumed that a pictorial representation of the runway configuration (i.e., outline) is part of the EHSI display data. Should this not be the case, necessary data to create the picture should be transmitted with the target airplane data.

As the final approach courses and the runways are to be displayed, some scaling difficulty is anticipated with this role. The display might cover an area of approximately 7 nautical miles square and hence the 150 foot width of the runway will be very narrow (almost a line). As the target symbol is only shown if the target airplane is actually on the runway and it will need to be relatively large to be seen, it is not reasonable to expect exact position with respect to the runway width will be available to the CDTI pilot. In addition, the choice of scale to show the information required for this role may not be compatible (or at least needs careful integration) with that used for other EHSI purposes.

Figure 4.1.4-2 illustrates a typical CDTI runway occupancy monitor role display.

4.1.4.6 Potential Benefits

The potential benefits of the CDTI runway occupancy monitor role are:

- 1) Improved system safety through a better informed pilot as to possible traffic on an active runway he is about to use. This is envisioned as principally useful in poor visibility conditions.

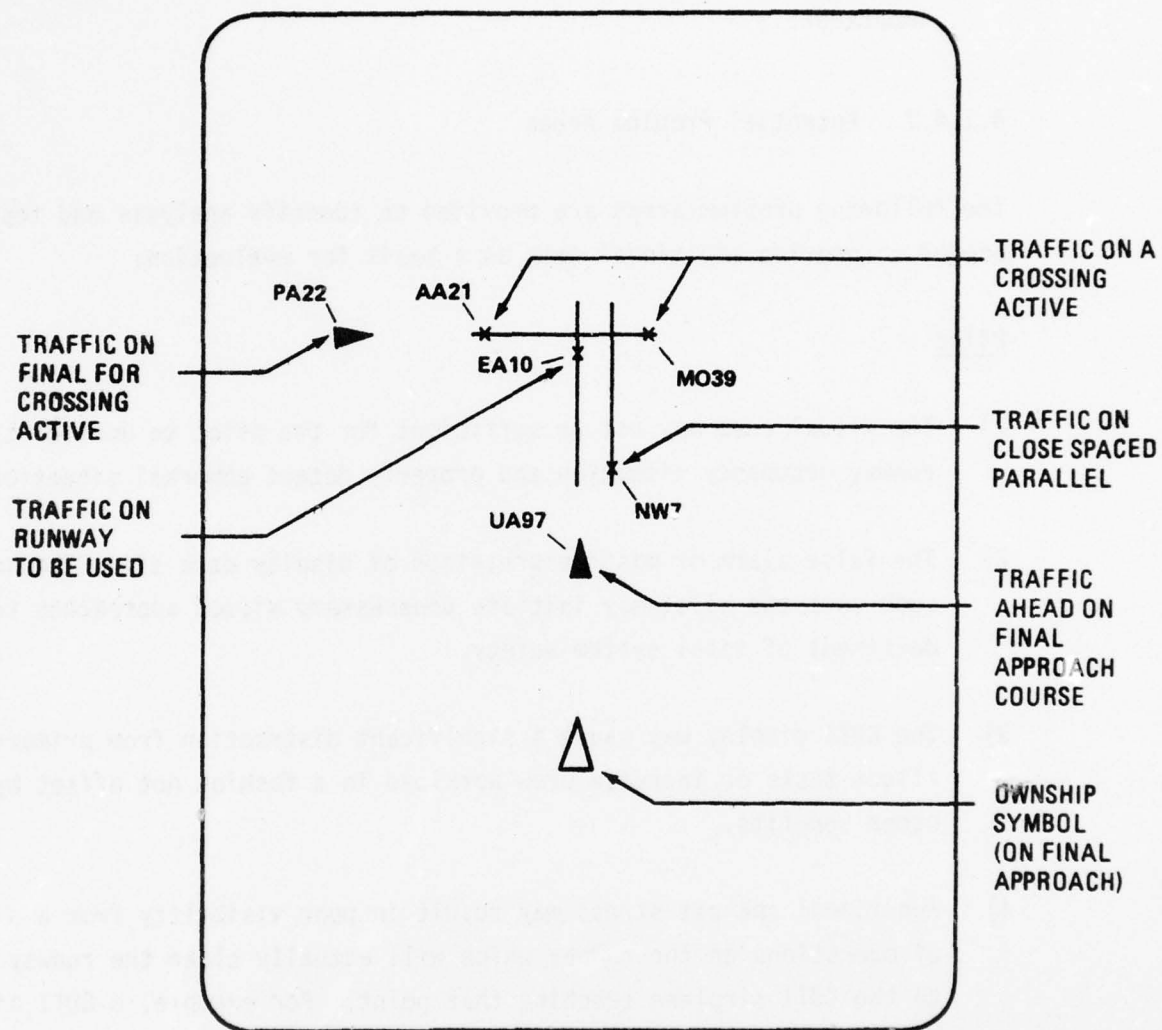


FIGURE 4.1.4-2 CDTI RUNWAY OCCUPANCY TYPICAL DISPLAY

- 2) Increased TMA capacity resulting from the pilot's acceptance of reduced separation criteria in situations where runway occupancy becomes a constraint. In addition, pilot acceptance of Category III operation may be enhanced by a knowledge of the runway occupancy situation. As airside separations are reduced, runway occupancy becomes the constraining factor and pilot assurance of a clear runway is apt to be very important.

4.1.4.7 Potential Problem Areas

The following problem areas are provided to identify analysis and testing needed to provide additional data as a basis for evaluation:

Pilot

- 1) The visual cues may not be sufficient for the pilot to monitor the runway occupancy situation and properly detect abnormal situations.
- 2) The false alarm or misinterpretation of display data situation may be such that the pilot may initiate unnecessary missed approaches to the detriment of total system safety.
- 3) The CDTI display may cause a significant distraction from primary flight tasks or increase crew workload in a fashion not offset by other benefits.
- 4) Additional cockpit stress may result in poor visibility from a display of operations on the runway which will actually clear the runway prior to the CDTI airplane reaching that point. For example, a CDTI airplane on final may see an "X" on the runway that is just a crossing taxi which will be clear well before the CDTI roll-out.

Operational

The "false alarm" rate problem and loss of intent information problem are potential problem areas.

Design

- 1) The best method of displaying and using runway occupancy information for monitoring must be developed.
- 2) Definition of exactly which traffic for crossing and parallel runways must be made to reduce display congestion and resulting distractions.

Performance

The CDTI display may not provide an adequate monitoring capability for the runway occupancy role.

4.1.4.8 Test Scenario Considerations

Considerations for designing test scenarios for simulation and flight test include the following:

- 1) The role should be evaluated with a model of a busy and complex runway situation. Close spaced arrivals, interspersed departures, and taxiing vehicles should all be included.
- 2) The role should be evaluated from the point of view of the arrival, the departure, and the taxiing CDTI airplanes.
- 3) Intentional blunders, runway conflicts, and apparent conflicts should occur randomly on infrequent intervals to test the CDTI pilot's ability to discover problems and to evaluate his reactions to them.

- 4) Pilot and controller workload should be heavy and realistic to prevent total concentration on the CDTI role.
- 5) The simulation and flight test should be designed to address the identified potential problem areas and provide a definition of the boundary limitations for CDTI usefulness for this role.
- 6) The ground sensor should be realistically included in the simulation.

4.2 Air Traffic Control Roles

The Air Traffic Control roles are those in which the pilot would use the CDTI to do tasks presently done by ATC. Specific roles considered for concept formulation were:

- 1) Arrival Merging,
- 2) Arrival In-Trail Spacing Control,
- 3) 4D Application to Metering and Spacing Environment,
- 4) Departure Separation,
- 5) En Route Passing and Crossing, and
- 6) Severe-Weather Avoidance Separation.

4.2.1 Arrival Merging

Arrival merging is the CDTI role in which the pilot rather than the ATC controller has the responsibility for navigating to merge into a stream of traffic while maintaining the prescribed spacing or minimum safe separation.

4.2.1.1 Problem Statement

To derandomize traffic arriving in the terminal area, the ATC system must collate aircraft from different route structures into a single adequately spaced stream for each runway. To accomplish this function, the system must be capable of:

- 1) Merging traffic from two or more organized routes at a control fix. Examples are the merging of traffic from two routes at an initial approach fix (IAF) and the merging of traffic streams from two IAF's before the outer marker.
- 2) Inserting an aircraft into a gap in an existing stream before some critical time or event occurs. Examples include insertion of a missed approach aircraft back into the primary arrival stream or the insertion

of an aircraft, which has been vectored for traffic control purposes, into the primary stream. These insertions must be accomplished prior to some critical time or event such as prior to the outer marker or a handoff point at which the stream must already be organized. The actual merge point and path used to achieve the merge are often impromptu and tactical in nature.

Inherent in the arrival merging problem is the determination of the sequence in which the aircraft will appear in the merged stream, and the control of relative velocities and spacing at the time of merging.

To be of operational value for the arrival merging role, a CDTI device must be capable of accomplishing all or a significant part of the above tasks without offsetting detrimental effects on other ATC or pilot functions.

4.2.1.2 Solution Approach

The general solution is for the pilot of the merging aircraft to use a cockpit display showing the relative position of the other aircraft to navigate to maintain safe separation while achieving a merge into a single output stream.

4.2.1.3 Discussion

In merging using controller-generated vectors, an exact determination of the existence of a solution via the initial strategy is not necessary as the controller responds to the situation as it develops. He can abort the current strategy for a new one if he doesn't like what he sees. This is done as a matter of course and the pilots may not even realize that the strategy change has occurred. In a CDTI system, the merging is accomplished by prior agreement via a "minicontract" or clearance. If the strategy is not safely workable, a new "minicontract" would need to be negotiated, or resumption of control by the ground would be required. The implications of passing the primary control responsibility back and forth between the

controller and the pilot are not well understood, particularly from a safety and workload point of view. One way of minimizing the number of control responsibility changes required is to be very sure that the initial minicontract can be safely executed before it becomes a clearance.

Two different techniques for obtaining this assurance appear feasible based on whether the ground ATC system is heavily automation dependent or heavily controller dependent. If automation dependent, then a mathematical/numerical solution to the required 4D tracks for each airplane to accomplish the merging could be generated and given to the airplane for execution (i.e., CDTI airplane follows a ground derived path and time box). This solution is deterministic because "intent" can be directed. Further investigation of such a concept identifies that the display of other traffic is extraneous to this merging technique and this is not actually a CDTI operation.

The second technique for assuring that the merge problem has a solution is for the controller, before initiating the minicontract, to control the problem to a point where the aircraft using the CDTI display can complete the merge without difficulty. Thus, the CDTI pilot performs actual final merge maneuver with a high probability of success, since the initial situation and intent have already been organized.

It is easiest to envision this CDTI role being used in a controller intensive ATC system; but it may also have merit in an automated system such as Metering and Spacing (M&S). In order to achieve gate times, the M&S system essentially unmerges airplanes (through path stretching) which must be remerged before the gate. This process may occur once in each sequencing area. At each remerging, CDTI merge techniques may contribute to the M&S control objectives by providing fine-tuning to the actual merge. Although this functionally accomplishes nothing not inherent in M&S, it might make M&S operation smoother while reducing communication and controller workload. Use of CDTI in this portion of M&S is worthy of test and evaluation.

An aspect of the CDTI self-merging role which must be considered is whether

air-to-air communications are required or desirable between the participating aircraft. Experiments are described in Reference 6 in which pilot-to-pilot communication as well as "announcements" were permitted while accomplishing a special merging problem of inserting STOL between CTOL on final approach. It is difficult to extrapolate from this three airplane situation to today's general approach control situation where many airplanes share a communication channel and the controller acts as "net control" and primary communications initiator. Even today in a busy terminal area, communication blockage from simultaneous transmission is common. Therefore, use of pilot initiated air-to-air communications does not appear to be a realistic concept for CDTI operations.

Another aspect of the CDTI merging problem is that an ATC controller is concerned with the position of the aircraft and output stream with respect to the earth. To maintain orientation to these fixed coordinates during CDTI merging implies the need for a pictorial navigation display showing intended stream geometry. This function could (and probably would) be part of the EHSI area navigation capability.

4.2.1.4 Operational Concept

The following operational concept is recommended based on consideration of the arrival merging task and available data.

4.2.1.4.1 Assumptions

The operational concept is based on the following assumptions:

- 1) The CDTI airplane will use relative traffic position as a basis for flying the airplane to maintain safe separation while achieving a merge with other airplanes.
- 2) ATC will monitor separation and retain ultimate responsibility for safe separation.

- 3) Overall situation control is via a centralized control authority with controller/pilot minicontracts allocated for CDTI merges.
- 4) One or more airplanes involved may be CDTI-equipped.
- 5) The CDTI airplane(s) may be required to perform all, or part of, the maneuvers required for successful merging without recourse to either air-to-air or air-to-ground communications after process initiation.
- 6) The velocities of all airplanes at the time of merge are identical and less than or equal to 250 KIAS from the IAF to the runway.
- 7) The CDTI display will contain relative position and altitude information as well as aircraft identification and sequence assignment for all aircraft in the required merging airspace.

4.2.1.4.2 Generalized Concept

The following general concept is proposed for potential application of CDTI-equipped airplanes to the ATC arrival merging role. Based on the controller determination that a relative merging situation exists which is compatible with CDTI execution, he will establish: (1) the desired stream speed at the time of merge; (2) the required initial conditions; (3) the CDTI clearance limits; (4) the merging altitude; (5) the desired merge point or merge boundary; and (6) the desired spacing at completion of the merge. Based on this information, the controller will negotiate a minicontract with the pilot to accomplish the merge. He will also inform the airplane(s) being merged with that a CDTI merge will occur. The CDTI airplane will then, using the CDTI display, accomplish the merge based on the terms of the minicontract. At the end of this process, the CDTI airplane will be inserted in-trail at the proper altitude, spacing and velocity on the output stream heading. The controller will continue in a monitor role intervening only in abnormal situations. Upon completion of the minicontract, the pilot will return control to ATC for further action.

4.2.1.4.3 Flow Diagram

Figure 4.2.1-1 illustrates the functional flow diagram for the arrival merging role. The diagram shows the controller or ATC ground system actions above the dashed line and the pilot's actions below.

4.2.1.4.4 Application Areas

For the arrival merging role, a CDTI device would have application to those control situations where: (1) traffic from different tracks from the en route system joins at an initial approach fix to form a single stream; (2) control is relative rather than time-based; (3) streams from different IAF's are joined; (4) airplanes reorganize into single streams after path stretching maneuvers; and (5) insertion of missed approaches and perhaps general aviation aircraft into an already organized traffic flow relatively close to the runway.

Item (4) above has an interesting potential application to the M&S environment in that the airplanes are intentionally maneuvered over different paths to achieve time objectives at the gates. This situation is basically merge intensive. It does not appear that CDTI would do any different job than that accomplished by M&S; but might improve the level of system performance achieved.

4.2.1.4.5 Operating Procedures

The following operational procedures are applicable to the CDTI arrival merging role:

- 1) The ground system shall have the sole responsibility for determining whether a CDTI merge shall be the control mechanism.
- 2) The ground system shall establish the initial conditions which will assure that a safe CDTI merge can be accomplished.

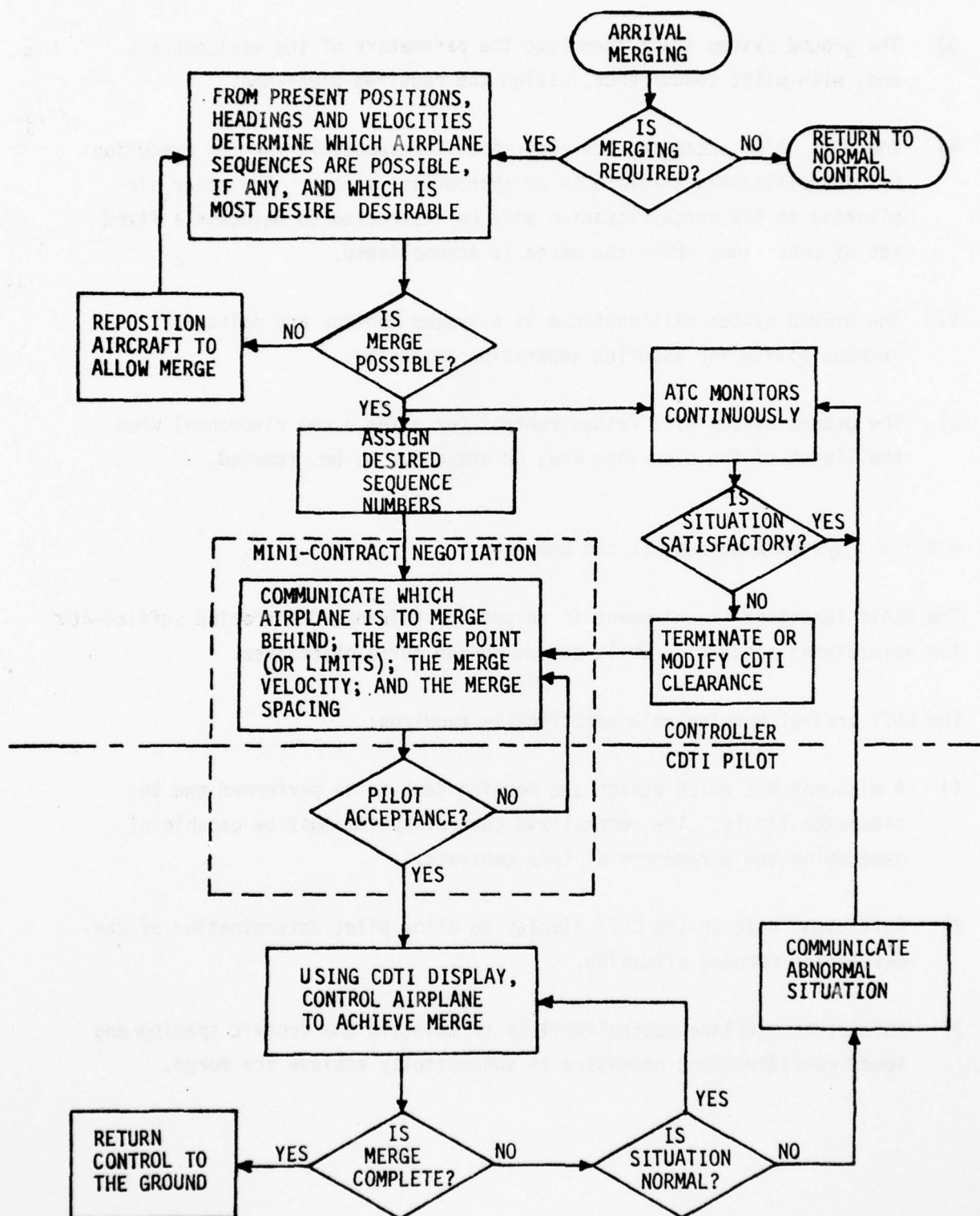


FIGURE 4.2.1 - 1 ARRIVAL MERGING FUNCTIONAL DIAGRAM

- 3) The ground system shall formulate the parameters of the minicontract and, with pilot concurrence, assign the required clearance.
- 4) The CDTI pilot accepting the clearance is responsible for its execution by controlling his airplane in an appropriate manner. The other airplane(s) in the merge situation will be instructed to maintain a fixed set of conditions while the merge is accomplished.
- 5) The ground system will continue as a system monitor and maintain responsibility for assuring separation integrity.
- 6) The ground system will resume control (or offer a new clearance) when the limits of the clearance are, or are about to be, reached.

4.2.1.5 System Requirements and Concept

The basic functional requirement is to provide guidance information sufficient for maintaining separation while achieving the merge objectives.

The CDTI arrival merging role specifically requires:

- 1) A minicontract which states the merging task to be performed and the clearance limits. The centralized control system must be capable of generating the parameters of this contract.
- 2) Sufficient data on the CDTI display to allow pilot determination of the developing merging situation.
- 3) Sufficient airplane controllability to maintain the dynamic spacing and speed considerations necessary to successfully achieve the merge.

4.2.1.5.1 Performance Requirements

Assuming that guidance necessary to achieve the merge will be based on a display of the relative position of other traffic, the following are the estimated system performance requirements. These values require verification and refinement by simulation and test.

Number of Targets - Two (the aircraft between which the merge is occurring).

Position Accuracy - Altitude data digitized in 100 foot increments and 1,000 foot accuracy in horizontal position.

Update Rate - 4 seconds.

Coverage Volume (Displayed) - Sufficient to include display of the target airplanes. Typically this could be ± 1000 feet in altitude and 10 miles from ownship's position.

Target Data - Basic target data is vertical and horizontal position from ownship. Additional data required is target identification and the sequence numbers.

Guidance Data - Information which may be required to implement a satisfactory guidance capability may include: (1) ownship predictive vector; (2) closing rate information; and (3) a bug to indicate expected insertion point. The CDTI pilot may mentally supply these values.

Guidance Accuracy - During the merging process, the system should allow the pilot to maintain separation within 10 percent (one sigma) of the minimum separation standard.

4.2.1.5.2 Display

The display for this role presents the target data and guidance information. The pertinent traffic to be displayed is at least the airplane(s) the CDTI airplane is merging with. It is anticipated that primary control would always be derived by using the aircraft ahead on the output stream as the target airplane. Thus, the CDTI airplanes are always achieving a merging relative to the airplane they follow in sequence. However, display of the airplane that will be behind them on the output stream is required to provide a complete situation picture.

For each displayed target, the displayed information should include: (1) identification; (2) sequence assignment; (3) position relative to ownship; (4) differential altitude; and (5) groundspeed.

Simulation evidence (Reference 6) indicates that a predictive vector or ownship is of value. In addition, a mark or symbol which is the target merge point could aid the pilot by more clearly depicting his merge objective.

While CDTI merging is inherently a relative air-to-air problem, clearance limits and general paths or routes are usually related to an earth-fixed system. As merging (by a controller) generally considers both of these systems, it will be necessary to display the intended route structure to provide the pilot a fixed frame of reference, both for accomplishing the merge and general traffic flow objectives. This fixed frame of reference will reduce the potential for the "radar assisted" collision.

Since airplanes in a merging situation may be maneuvering, there does not appear to be a simple set of cues to provide guidance to the CDTI pilot beyond those discussed above. A fixed reference CDTI map system (like the controller's display) could remove some of the confusion of the relative display, but this is not consistent with either the EHSI implementation or the pilot's frame of reference for achieving ownship's objectives over the ground.

The display scale requirement is a function of the maximum distance over which aircraft are to be displayed and the resolution requirements to determine if proper separation is being maintained during the merge. Since the CDTI data is to be presented as an EHSI function, the scale required for other EHSI roles used at the same time must be considered. Integration of CDTI and other EHSI information will need to be accomplished during device design programs to assure minimizing in-air scale changing and potential for disorientation.

Figure 4.2.1-2 illustrates the information content of the display for the arrival merging role.

4.2.1.6 Potential Benefits

The principal benefits of CDTI arrival merging are:

- 1) Increased runway capacity resulting from more precise merging, reduction of controller workload, and pilot acceptance of reduced separations.
- 2) Reduced ATC operating costs due to a reduction of the per operation controller work force. This results from relieving the workload and communication associated with the tactics of merging.
- 3) Improved safety by providing the pilot with more lead time for required heading, speed, altitude, or configuration changes and reduced distraction from outside-the-cockpit communications.

4.2.1.7 Potential Problem Areas

The following problem areas are provided to identify analysis and testing needed to provide additional data as a basis of further evaluation.

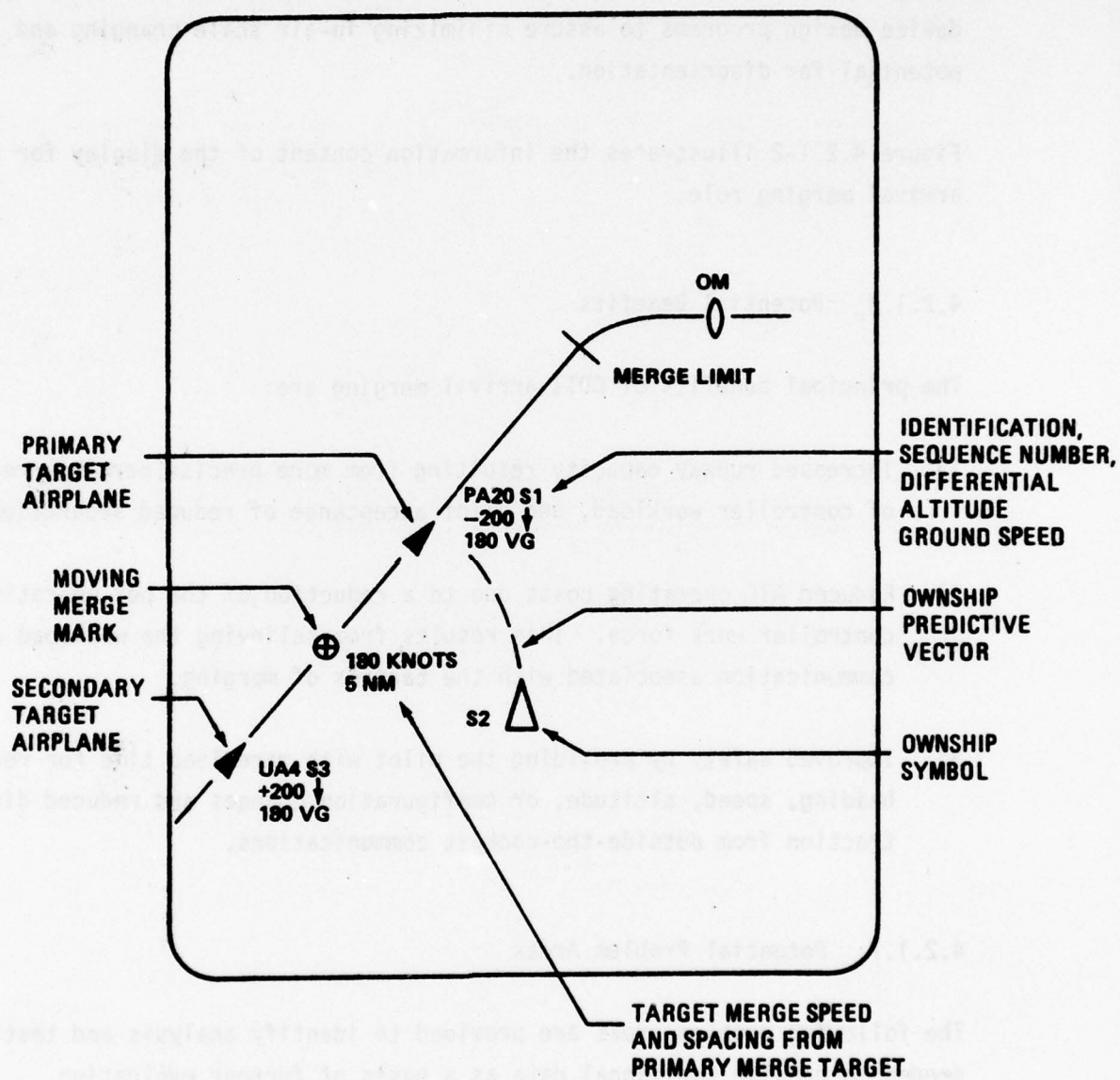


FIGURE 4.2.1-2 CDTI ARRIVAL MERGING DISPLAY

Pilot

- 1) The visual cues presented may not be sufficient for the pilot to accomplish the arrival merging task reliably.
- 2) The increase in pilot workload and possible diversion of the pilot's attention from critical flight instruments, due to CDTI guidance requirements, may be a problem.
- 3) The history of "radar-assisted" ship collisions does not make contemplation of maneuvering CDTI roles easier. Reference 7 discusses and indicates this problem may not apply to CDTI. This reference indicates that improper use of the relative display information and immoderate speeds were the basic reasons in such collisions. As airplane speeds are much higher than ship speeds and much less controllable, a potential collision situation can develop very rapidly. The improper use of the relative information seems well correlated to lack of intent information and ambiguous "Rules of the Road" when applied to marine radar use. The use of CDTI in this maneuvering role should be analyzed and designed to preclude this potential problem. Intent information, or more properly, the pilot's unambiguous understanding of intent information, seems to be the most important single factor, assuming simple and unambiguous rules are available.

Operational

- 1) The minicontract form of clearance (with the implied handoff from ground-to-air of the ATC function) may not be as safe and reliable as the present system of control from the ground only. There is possible confusion over who is responsible.
- 2) An increase in air-ground-air communication may occur in cases where the controller does not understand the pilot's reactions and intent in spacing deterioration situations. In a sense, this is similar to one controller monitoring another without understanding his intent and could result in high stress situations.

- 3) The human factor implications of this type of decentralized control both during handoffs and during acceptance of a control position during shift changes and relief breaks are undetermined.
- 4) The possibility exists for a CDTI airplane to allow a merging task to deteriorate in a way that would make it impossible for a controller to resolve the problem upon intervention. The potential for the control problem to degenerate further before discovery of solution limitations exists with this type of responsibility division.
- 5) The controller may not always be able to determine the situations from which a successful CDTI merge can be accomplished without difficulty.
- 6) Unexpected changes in the target aircraft's flight may produce situations that the CDTI airplane either cannot cope with or may react to in an undesirable fashion. This technique is directly related to formation flying in which the action of the leader has direct effect on the follower. This problem may be compounded by traffic under normal ATC control and those using CDTI must be thoroughly investigated.
- 7) In the mixed traffic environment, the controller may not be able to keep straight the airplanes he is controlling versus the CDTI airplanes he is monitoring.

Design

- 1) The specific details and terminology of the minicontract form of clearance must be developed and tested for the many situations that can arise in accomplishing CDTI arrival merging.
- 2) The best methods of displaying and using relative traffic position data to accomplish the merging must be developed. Such solutions as defining a 4D path assignment are not acceptable as this is 4D RNAV or strategic control and not CDTI relative navigation.

- 3) The spacing and speed accuracy at the merge point are a function of data source, display parameters and format. Crew workload should be tested to determine the system data requirements.

Performance

- 1) The CDTI airplane may not be able to accomplish merging within the required accuracy.

4.2.1.8 Test Scenario Considerations

Considerations in designing scenarios for simulation or flight tests include the following:

- 1) The traffic model for investigating ATC operational problems should use a high density arrival-only runway with actual traffic demand and aircraft type sequence. An M&S geometry as well as a conventionally controlled TMA should be tested and should include arrival merging situations which feed the initial approach fix (IAF). An alternative traffic mix could be from schedule data modified to include a realistic mix of other types.
- 2) Merging for impromptu situations such as a missed approach or general aviation aircraft should be investigated.
- 3) The scenario should include traffic mixes where all and some airplanes are CDTI-equipped.
- 4) The scenario should include airspace limitations which constrain the controller's solution space should the problem revert to him.
- 5) The scenario should be complete for both pilot and controller workload. Maximum workload situations should be considered with their resulting stress and distraction factors.

- 6) Rare event occurrences should be programmed to investigate CDTI response and system recovery as to performance and safety.
- 7) Arrival altitude profiles should represent a range of constraints such as noise abatement and airspace limitations as required at major airports.
- 8) The analysis, simulation, and flight tests should be designed to address the identified potential problem areas and provide a definition of the boundary limitations for CDTI usefulness.

4.2.2 Arrival In-Trail Spacing Control

Arrival in-trail spacing control is the CDTI role in which the pilot rather than the ATC controller has the responsibility for navigating to maintain a prescribed longitudinal spacing from the preceding airplane.

4.2.2.1 Problem Statement

In order to feed arrivals to a runway safely and efficiently, the controller (or an automated system) must place all arrivals on a common path headed for the runway, with spacing such that separation and/or runway occupancy criteria are not violated during either the terminal area transition or the final approach and landing phase. Local flow control objectives of adjusting flow rate into the terminal area to match that of runway capacity are also partly achieved through choice of in-trail spacing on a common path or route. Partial streams may be created for the purpose of organizing traffic to allow a merging of two partial streams into a single output stream. Spacings need to be tailored to the merge objective and output stream spacing requirements. Spacing in a stream is also affected by requirements to insert missed approaches or departures.

4.2.2.2 Solution Approach

The general solution approach is for the pilot(s) to use a cockpit display of relative navigation information to maintain an assigned spacing from the aircraft ahead in the arrival stream.

4.2.2.3 Discussion

The spacing requirement at any point in an airplane stream is a complex function of many dynamically changing variables. The initial spacing can not be set equal to the required separation and maintained constant during the transition and landing. Figure 4.2.2-1 shows the variation in spacing between in-trail arrivals as they reduce airspeed while transiting the terminal area.

The spacing desired between two in-trail airplanes at any point in the terminal area is a function of the following parameters:

- 1) Required present separation
- 2) Required future separation
- 3) Ground speed differentials (present or future)
- 4) Runway operations rate
- 5) TMA entry flow rate
- 6) Departure interleaving requirements
- 7) Stream merging requirements
- 8) Airspace conflicts between the arrival stream and departures, overflights, or arrivals for other runways.
- 9) Missed approach or emergency insertions
- 10) The particular control strategy presently being used both by the facility and by the individual controller.

The effects of each of these parameters are discussed below.

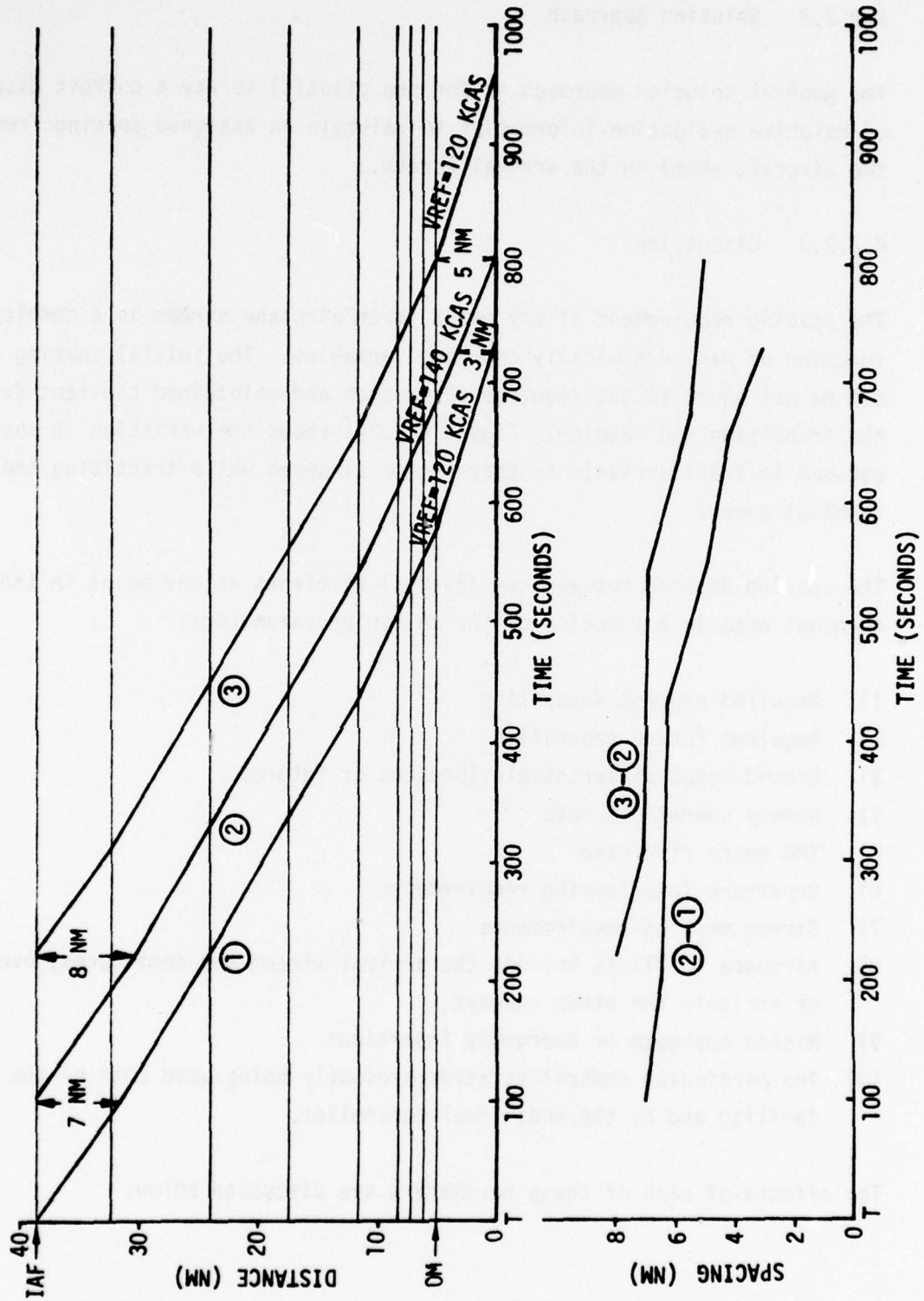


FIGURE 4.2.2-1 SPACING VARIATION DUE TO TMA SPEED REDUCTION

Required Present Separation - This spacing requirement requires no perception of the future situation. The requirement is to space airplanes such that, in-trail, they have a low probability of being closer than the distance prescribed by the rules and procedures for the airplane types and phase of flight. The spacing requirements imposed by the present required separation dictate the minimum spacing which can be established. This spacing is usually considered as a distance requirement rather than a time requirement. As both the controller's scope and CDTI display are position (and hence distance) oriented, the distance parameter is most easily sensed.

Required Future Separation - The actual spacing assigned at any point in a string of aircraft is the sum of that needed for present separation plus that space required to assure safe separation at future points in the airspace and runway geometry. Thus, the contribution to present spacing implied by future considerations includes all items from 2) to 10) in the parameter list above.

The required future separation is that distance or time prescribed by the applicable separation rule for any future point in the approach.

Ground Speed Differences between aircraft in a stream occur for a number of reasons. Among these are differences in: (1) aircraft performance capability; (2) altitude for same airspeed; (3) weights; (4) pilot preferences and pilotage error; (5) controller strategy preference; and (6) wind effect. Any differential in ground speed integrates with time and can cause spacing to increase or decrease depending on the magnitude of the difference. Many of these effects are known to the controller and help to establish his best spacing estimate. He will react tactically to others as the spacing objective deteriorates, either by maintaining the stream through speed control or through path stretching via vectoring.

Flow rate considerations also create a requirement for spacing deviations. To control airplanes passed any point (e.g., an IAF or Outer Marker) in the system, the number of airplanes per unit of time is a function of their velocities

and the required separation distance. In addition, for a terminal area which is operating at capacity for any period of time, the runway operations rate must be equal to the TMA entry flow rate. To maintain the same flow rate at the threshold as at the TMA boundary requires that entry airplanes have the same time separation as the time separation on final approach. As the distance separation requirement is the usual specification, the critical point in the system tends to be where the airplanes have the lowest velocities (i.e., on final approach). For clarification purposes, consider the example where successive airplanes must have 3 nautical miles separation for safety and assume that the airplanes can maintain 120 knots ground speed on final. The separation time on final is then

$$t_s = \frac{d_s}{V} = \frac{3 \text{ nm}}{120 \text{ nm/hr}} \times \frac{3600 \text{ seconds}}{1 \text{ hour}} = 90 \text{ seconds}$$

However, airplanes entering a TMA are more likely to be around 250 KCAS at maybe 10,000 feet which implies zero wind ground speeds of 290 knots. To maintain the same flow rate as on final approach, the separation time would still be 90 seconds, but the required spacing would be

$$d_{sp} = V \times t_s = 290 \text{ nm/hr} \times \frac{90 \text{ seconds}}{3600 \text{ seconds/hour}} = 7.25 \text{ nm}$$

If the TMA were fed with balanced traffic loading across four IAF's, then the spacing over any one IAF would need to be on the order of 29 nautical miles. This example situation can be observed for instance at Atlanta where two IAF's feed each runway of a parallel pair. When very busy, Atlanta TRACON may request the adjoining en route sectors to deliver airplanes to the IAF's at 15 nm spacings in-trail.

The spacing at any point in the system is similarly related to the final separation time by the stream velocity at that point. In general, as the airplanes are slowed in airspeed (and hence ground speed) as the terminal area is transitioned, the flow rate related contribution to spacing is also

decreased (Figure 4.2.2-1). For a simplifying assumption that all airplanes land at the same speed, the spacing at any other TMA point will not be less than the threshold separation if velocities are constant or monotonically decreasing throughout the terminal area.

The above considerations are descriptive of requirements imposed by flow rate on a busy, steady-state traffic stream. In many ATC situations, the transient response to busy periods is probably more significant to potential CDTI use for in-trail spacing. As a traffic peak starts to build, the controller will initially attempt to react by accepting more airplanes (i.e., a higher flow rate) into the terminal area than the runway can handle. Thus the TMA airspace becomes more densely populated than the steady-state would dictate. He does this in order to forestall a need for "stacking" at the ARTCC/TRACON interface (or elsewhere). He hopes that the peak can be passed without ever going to stacking, which for a number of reasons reduces total system throughput efficiency. In order to accommodate this increased density, he has several choices of management techniques. One option is to use speed control and close-up spacing to achieve a stream with spacing and speeds close to that required on final approach. This technique ultimately results in an accordion effect which requires airplanes in the en route airspace to be near landing speed and configuration and thus is only applicable to short-term peaking. Another technique is to increase the stream path length within the TMA via path stretching to accommodate the additional airplanes for a longer period of time before effecting the en route sectors. An ATC "trombone" is an example of this technique. Still another option is to breakup an entry stream through different vectoring instructions to the individual airplanes and then recombining the stream at a later point in the approach. This technique is the basis for the M&S operation where a stream, as such, only exists at a few limited segments of the total approach path. Each airplane takes a path consistent with the time objectives for that airplane. Thus, in an M&S environment, airplanes do not, as a matter of course, follow the airplane ahead over the same

path in an in-trail fashion except for limited portions of the approach. The one additional technique at the controllers disposal for accommodating increased density is that of maintaining altitude separation until the airplanes can be re-established on a common stream.

Another aspect of the in-trail spacing requirements is the creation of "gaps" in the stream for events to take place in the future such as allowing a departure between two arrivals, or the spacing slack to allow the merging of two streams into a single stream, or the insertion of a missed approach or emergency aircraft. Each of these situations requires spacing, above that required for separation, for a future event. In some TMA's it may even be necessary to provide an arrival stream gap to accommodate a crossing departure climbing through the arrival stream.

It must be recognized that a controller may use any or all of these techniques in responding to the dynamics of the real-time traffic situation. The spacing function is likewise a dynamic variable in many cases if in fact an in-trail stream even exists. Locally, at least on the final approach course, an in-trail stream certainly occurs. One further aspect of this situation is that an automated system such as ARTS-III does not have the spacing intent of the controller resident in its computer and even with M&S does not solve the general in-trail spacing solution to TMA transition. If an automated system were to control the arrival traffic in-trail over a common path such that the spacing function was deterministic, the system would be 4D (strategic) in nature and the knowledge of other traffic (CDTI operation) extraneous to the control function.

4.2.2.4 Operational Concept

The following operational concept is recommended based on consideration of the arrival in-trail spacing role and available data:

4.2.2.4.1 Assumptions

In formulating the operational concept for arrival in-trail spacing the following assumptions were used:

- 1) A centralized ATC system will accomplish overall arrival control with CDTI use for in-trail arrival spacing by executing a minicontract or clearance for a well-defined CDTI objective.
- 2) A properly CDTI-equipped airplane can achieve in-trail constant spacing functions without additional aid from the controller (i.e., beyond initial setup and conditions).
- 3) The centralized ATC will provide monitoring for execution of CDTI mini-contracts and have the option of resuming central control at the discretion of the controller.
- 4) Air-to-air voice communication is undesirable and unnecessary. Contemplation of the primary control frequency congestion and/or the necessity for new equipment and channel allocations do not indicate any concept requiring air-to-air communication.
- 5) CDTI equipment is optional.

4.2.2.4.2 Generalized Concept

The following general concept is proposed for potential application of CDTI-equipped airplanes to the ATC in-trail spacing role. Based on the controller selection that a relative in-trail spacing situation exists which is compatible

with CDTI execution, he will determine: (1) the desired stream speed(s); (2) establish initial conditions; (3) the CDTI clearance limits; and (4) the desired spacing function. Based on this information, the controller will negotiate a minicontract with the pilot to accomplish the in-trail spacing job. This concept envisions CDTI will be used to maintain a constant spacing during the time that the preceding airplane is flying a constant speed. The CDTI airplane will then, using the CDTI display, maintain the spacing function contained in the clearance. The controller will continue in a monitor role intervening only in abnormal situations. Upon completion of the "mini-contract", the pilot will return control to ATC for further action.

4.2.2.4.3 Flow Diagram

Figure 4.2.2-2 illustrates the functional flow diagram for the arrival in-trail spacing role. The diagram shows the controller or ATC ground system actions above the dashed line and the controllers actions below.

4.2.2.4.4 Application Areas

For the arrival in-trail spacing role, a CDTI device would have greatest applicability to those control situations where: (1) airplanes are carried in-trail for considerable portions of the terminal area transition at constant spacing, and (2) where the control mechanization is relative rather than time based. This situation is relatively common in today's radar control environment, with the controller providing speed control or minor path excursion instructions to achieve stream spacing. Arrival streams which are straight-in along the extended runway centerline are a simple example of this situation.

A special case of the above technique is sometimes used on final approach during VMC. In this case, the pilot is requested to maintain a particular spacing behind the airplane ahead on final. CDTI devices may provide better cues both for target airplane identification and for accomplishing the spacing.

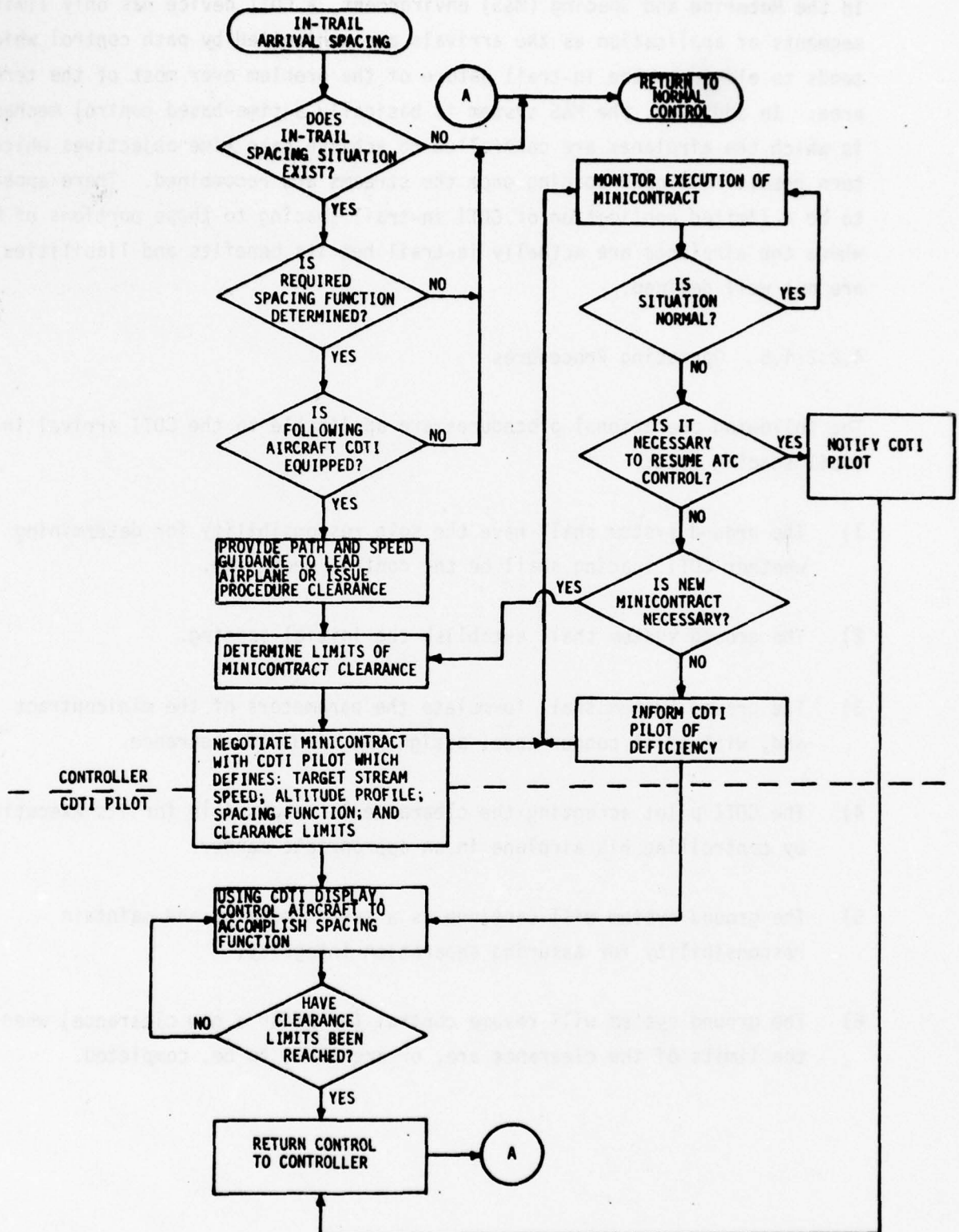


FIGURE 4.2.2 - 2 IN-TRAIL ARRIVAL SPACING FUNCTIONAL DIAGRAM

In the Metering and Spacing (M&S) environment, a CDTI device has only limited segments of application as the arrivals are controlled by path control which tends to eliminate the in-trail nature of the problem over most of the terminal area. In addition, the M&S system is basically a time-based control mechanism in which the airplanes are controlled to achieve gate time objectives which in turn result in proper spacing once the streams are recombined. There appears to be a limited application of CDTI in-trail spacing to those portions of M&S where the airplanes are actually in-trail but its benefits and liabilities are not well defined.

4.2.2.4.5 Operating Procedures

The following operational procedures are applicable to the CDTI arrival in-trail spacing role:

- 1) The ground system shall have the sole responsibility for determining whether CDTI spacing shall be the control mechanism.
- 2) The ground system shall establish the initial spacing.
- 3) The ground system shall formulate the parameters of the minicontract and, with pilot concurrence, assign the required clearance.
- 4) The CDTI pilot accepting the clearance is responsible for its execution by controlling his airplane in an appropriate manner.
- 5) The ground system will continue as a system monitor and maintain responsibility for assuring separation integrity.
- 6) The ground system will resume control (or offer a new clearance) when the limits of the clearance are, or are about to be, completed.

4.2.2.5 System Requirements and Concept

The CDTI arrival in-trail spacing role requires a system functionally comprised of: (1) a CDTI display; (2) a sensor system to acquire data for all pertinent aircraft; (3) computational capability to select and format pertinent data; (4) a means of communicating information from the data base to the CDTI display; and (5) a centralized control facility for initiating and monitoring role execution.

The CDTI spacing role specifically requires:

- 1) A minicontract which states the spacing task to be performed and the clearance limits. The centralized control system must be capable of generating the parameters of this contract.
- 2) Sufficient data on the CDTI display to allow pilot determination of the in-trail separation situation.
- 3) Sufficient airplane controllability to maintain the dynamic spacing requirement.

4.2.2.5.1 Performance Requirements

Principal performance requirements for this CDTI role are defined by the following parameters:

- 1) Pertinent traffic to be displayed - The pertinent traffic to be displayed is at least the airplane to which the CDTI airplane is maintaining relative spacing. Variations to this single target approach would include display of two airplanes ahead and the airplane behind, subject to some maximum distance beyond which airplanes would not be shown. If this variation were found to be desirable, a maximum distance for trailing aircraft might be 1-1/2 times the minimum separation distance. For airplanes ahead on the path a maximum of 20 nautical miles appears appropriate.

- 2) Information required for each displayed traffic target - For each displayed target, the displayed information should include: (1) identification; (2) position relative to heading of ownship; (3) differential altitude; and (4) differential groundspeed along track.
- 3) Information or cues pertaining to ownship - Information or cues pertaining to ownship can range from none other than ownships symbol to complex command bars or instructions for achieving the spacing function. Previous simulation work (Reference 6) indicates considerable preference for inclusion of at least an ownship predictive vector indicating position at selected times in the future. This appears to be an adequate set of cues. A range circle or mark indicating the desired spacing distance would give a positive indication of the role objective.
- 4) Display scale requirements - This display scale requirement is a function of the maximum distance over which airplanes are to be displayed and the resolution requirements to determine if proper separation is being maintained. As the CDTI data is to be presented as an EHSI function, the scale required for other EHSI roles used at the same time must also be considered. This may lead to incompatible scaling requirements. Integration of CDTI and other EHSI information will need to be accomplished during device design programs.
- 5) Role performance - Role performance requirements are bounded by the need to maintain tight spacing while at the same time reducing go-arounds or controller interventions due to spacing deterioration which causes minimum separation criteria to be violated. To be a viable candidate for the spacing role, a CDTI system (i.e., ground and air equipment plus human responses) must be able to achieve the relative airplane control to an accuracy that is a small fraction of the minimum separation distance. A reasonable target value for spacing accuracy would be less than ten percent (one sigma) of the minimum separation distance. The accuracy is a function of the minimum separation distance rather than the assigned spacing distance as insertions in the stream may have to be made at

various points in the stream. Thus, with three nautical miles minimum separation, the CDTI airplane would be expected to be within ± 0.3 n.mi. of his assigned spacing 95 percent of the time.

- 6) Coverage Volume (Displayed) - The display coverage volume must be sufficient to show the target aircraft from which in-trail spacing is being maintained. As the formulated concept assumes CDTI use for in-trail situations of constant spacing, a reasonable value for display volume is 15 n.mi. ahead of ownship. Altitude considerations should be consistent with the distance, recognizing that the airplanes are descending and hence the target airplane is likely to be at a considerably lower altitude at 15 n.mi.

4.2.2.5.2 Display

The display of other traffic for this role is baselined to be on the plan-position EHSI CRT. The basic display requirements are as discussed in the performance requirements above. A typical display illustrating this is shown in Figure 4.2.2-3.

If the desired spacing mark is overlaid on the target aircraft symbol, the spacing is correct. If the spacing mark is ahead of the target airplane as shown, the spacing is less than desired and the CDTI pilot needs to correct by slowing slightly. The target airplane's data block indicates it is 200 feet above the CDTI airplane and descending and its groundspeed is 15 knots less than the CDTI airplane.

4.2.2.6 Potential Benefits

The principal benefits of CDTI arrival in-trail spacing are:

- 1) Increased runway capacity due to improved relative spacing and reduced controller workload,
- 2) Reduced ATC operating costs due to reduced controller work force on a per operation basis, and
- 3) Improved safety by providing the pilot with more lead time for required speed and configuration changes and reduced distraction from outside-the-cockpit communications.

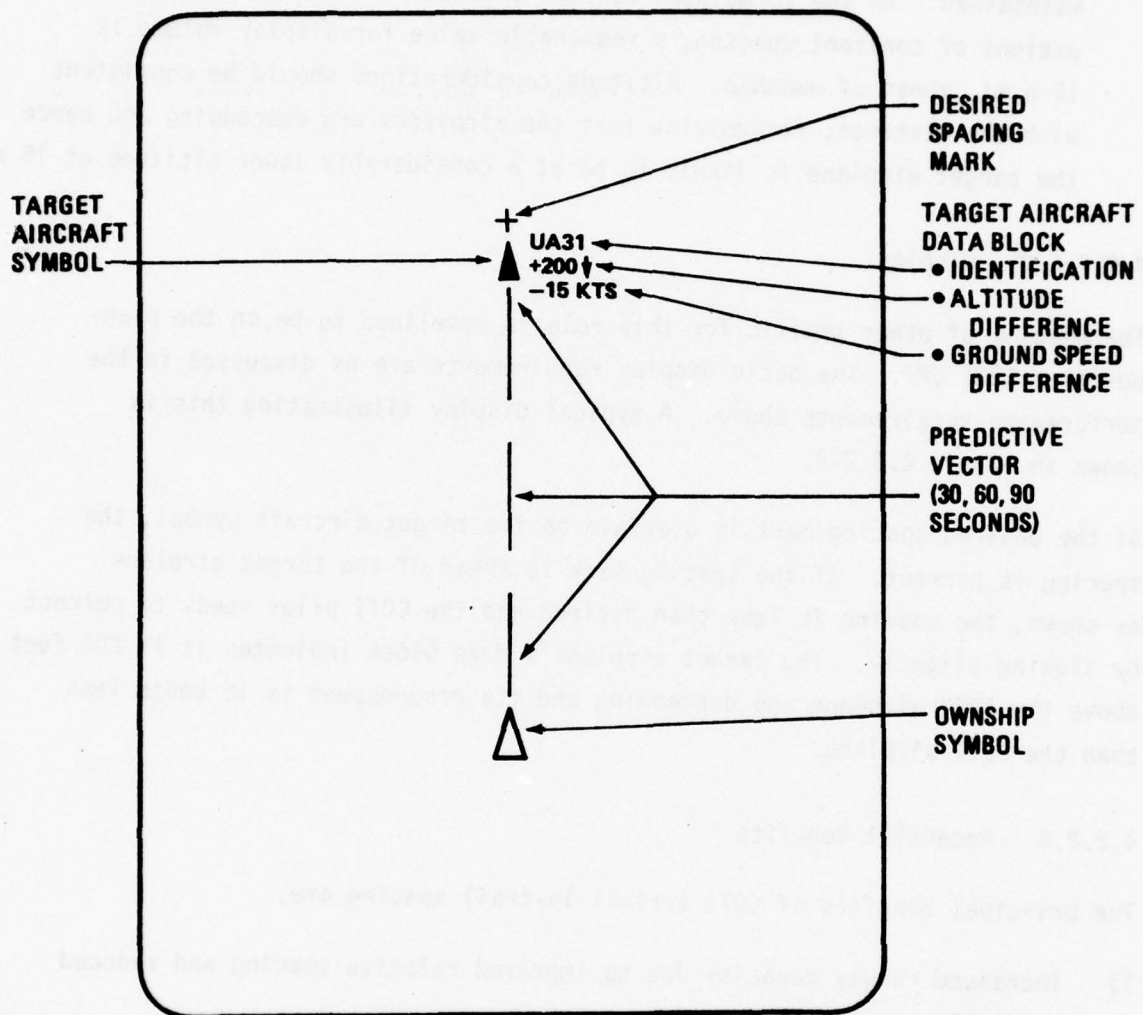


FIGURE 4.2-3 CDTI ARRIVAL IN-TRAIL SPACING CONTROL

Additional benefits which may result are:

- 1) Reduced airspace requirements if this type of control can reduce the number of TMA's where vector, rather than speed, control is used, and
- 2) Pilot acceptance of reduced separation standards.

4.2.2.7 Potential Problem Areas

The following problem areas are provided to identify analysis and testing needed to provide additional data as a basis of further evaluation.

Pilot

- 1) The increase in pilot workload and possible diversion of the pilot's attention from critical flight instruments due to the CDTI guidance requirements may be a problem.
- 2) The visual cues presented may not be sufficient for the pilot to manage the CDTI spacing task reliably.

Operational

- 1) The minicontract form of clearance may not be as safe and reliable as the present system of control from the ground only.
- 2) The performance of the controller in a monitoring role without understanding the pilots reactions and intent in a situation where assigned spacing has deteriorated may cause an increase in air-ground communications.
- 3) The human factor implications of this type of decentralized control are critical.

- 4) A deteriorating situation in which controller intervention cannot solve a spacing problem may occur. An example might be where the pilot has used all the speed control possible and still is closing-up the spacing, now leaving the controller with a vectoring problem in a situation he had anticipated was in-trail. The potential for the control problem to degenerate much further before discovery of solution limitations exists with this type of responsibility division.
- 5) The CDTI may not be able to cope with either variable spacing functions or changing stream speeds without an accordion effect.
- 6) Unexpected changes in the target aircraft's flight may produce situations with which the CDTI airplane cannot cope or conversely may cope with in an undesirable fashion. This technique is directly related to formation flying in which the action of the leader has direct effect on the follower. This problem may be compounded further with a mix of equipped and unequipped traffic. Interactions between traffic under normal ATC control and those using CDTI must be thoroughly investigated.

Design

- 1) The specific details and terminology of the minicontract form of clearance must be developed and tested for the many situations that can arise in accomplishing arrival in-trail spacing.
- 2) The best methods of displaying and using relative traffic position data to maintain in-trail spacing must be developed.
- 3) The spacing accuracy as a function of data source, display parameters and format, and crew workload should be tested to determine the system data requirements.

Performance

A CDTI airplane may not be able to maintain an assigned spacing within the required accuracy.

4.2.2.8 Test Scenario Considerations

Considerations in designing scenarios for simulation or flight tests include the following:

- 1) The traffic model for investigating ATC operational problems should use a high density arrival-only runway with actual traffic demand and aircraft type sequence. A variation using a mixed departure/arrival runway should be tested to investigate the effect of departure slots on spacing and operational performance. An alternative traffic mix could be from traffic schedules modified to include a realistic mix of other types.
- 2) The scenario should include traffic mixes where all and some airplanes are CDTI-equipped.
- 3) The scenario should include airspace limitations which constrain the controller's solution space should the problem revert to him.
- 4) The scenario should be complete for both pilot and controller workload. Maximum workload situations should be considered with their resulting stress and distraction factors.
- 5) Rare event occurrences should be programmed to investigate CDTI response and system recovery as to performance and safety.
- 6) Arrival altitude profiles should represent a range of constraints such as noise abatement and airspace limitations as required at major airports.

4.2.3 Departure Separation

Departure separation is the CDTI role in which the pilot rather than the ATC controller has the responsibility for navigating to maintain the minimum prescribed safe separation from another departure.

4.2.3.1 Problem Statement

Aircraft departing from an airport (especially from the same runway) along the same track must be controlled to maintain safe separation until reaching diverging courses or separate cruise altitudes.

Sequentially departing aircraft usually have different climb and speed profiles. The potential for conflict due to overtake is always present among aircraft in the same performance class, or in cases where a higher performance aircraft follows a lower performance aircraft. This presents a significant workload for the controller. Since departure profiles are difficult to predict accurately, the solution usually is to constrain the potential for conflict by:

- 1) increasing the spacing between departures to allow for some loss of separation during climbout, or
- 2) limiting the clearance in terms of path, speed or altitude to insure separation.

4.2.3.2 Solution Approach

The general solution is for the pilot of the departing aircraft to use a cockpit display showing the relative position of another departure (probably the preceding departure) to navigate to maintain safe separation from that departure.

4.2.3.3 Discussion

Figures 4.2.3-1 and 4.2.3-2 are examples of departure speed/altitude versus distance profiles which indicate some of the dynamics with which a CDTI pilot would have to cope.

The use of the CDTI to maintain longitudinal or vertical separation will be difficult prior to the preceding aircraft completing its initial climbout and noise abatement profile and stabilizing on steady climb to cruise altitude conditions.

Large variations in climb rate and speed occur during initial climb and noise abatement. The examples presented in Figures 4.2.4-1 and 4.2.4-2 indicate that the initial speeds and rates of climb for two typical commercial aircraft can range from 148 KIAS to 180 KIAS and 2600 ft/min. to 1300 ft/min respectively. The point at which each aircraft attains an altitude of 3000 feet (when acceleration to 250 KIAS begins) can range from 4 to 13 nautical miles from brake release.

The two noise abatement procedures illustrated are typical of industry practice and somewhat complex in nature. The ATA procedure (Reference 15) provides for:

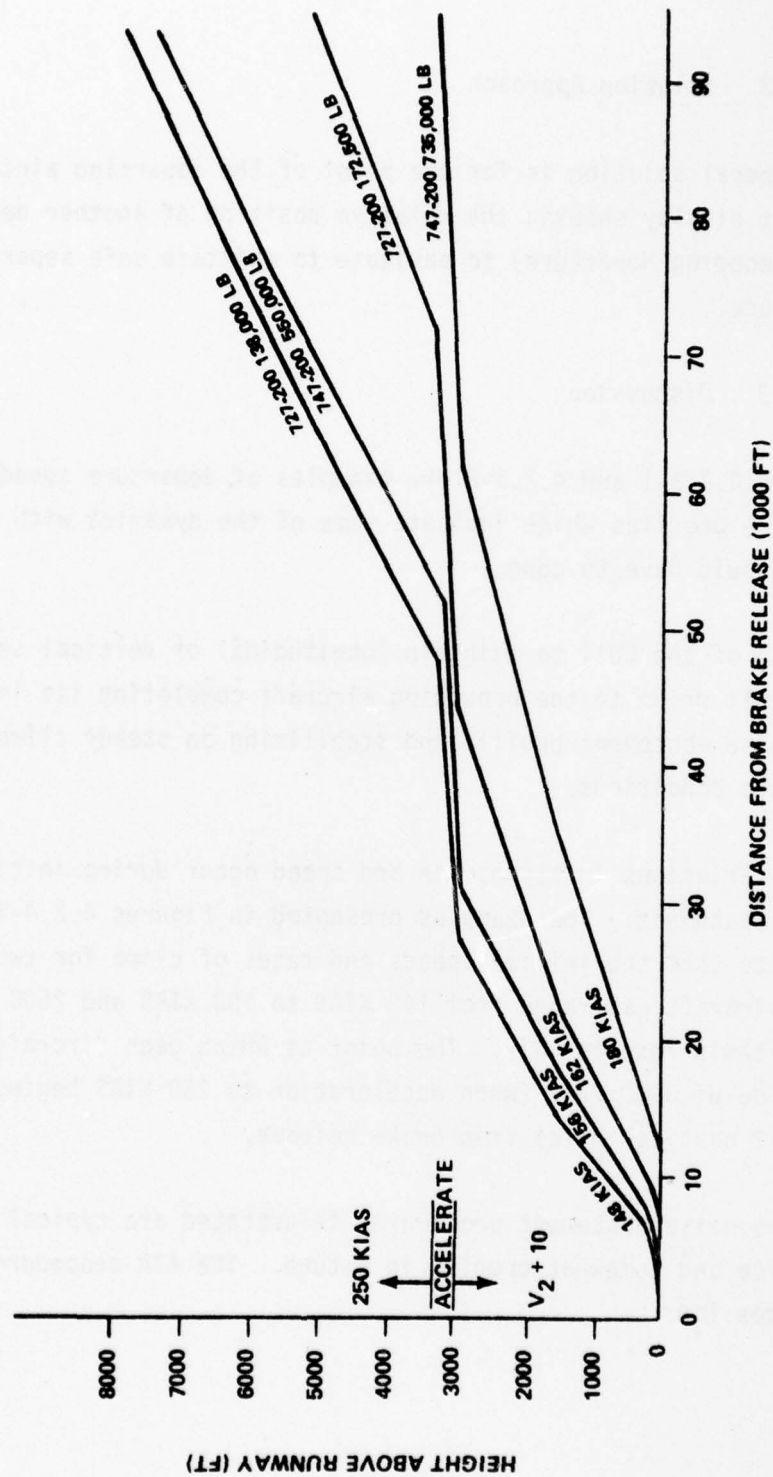


FIGURE 4.2.3-1 ATA NOISE ABATEMENT PROCEDURE

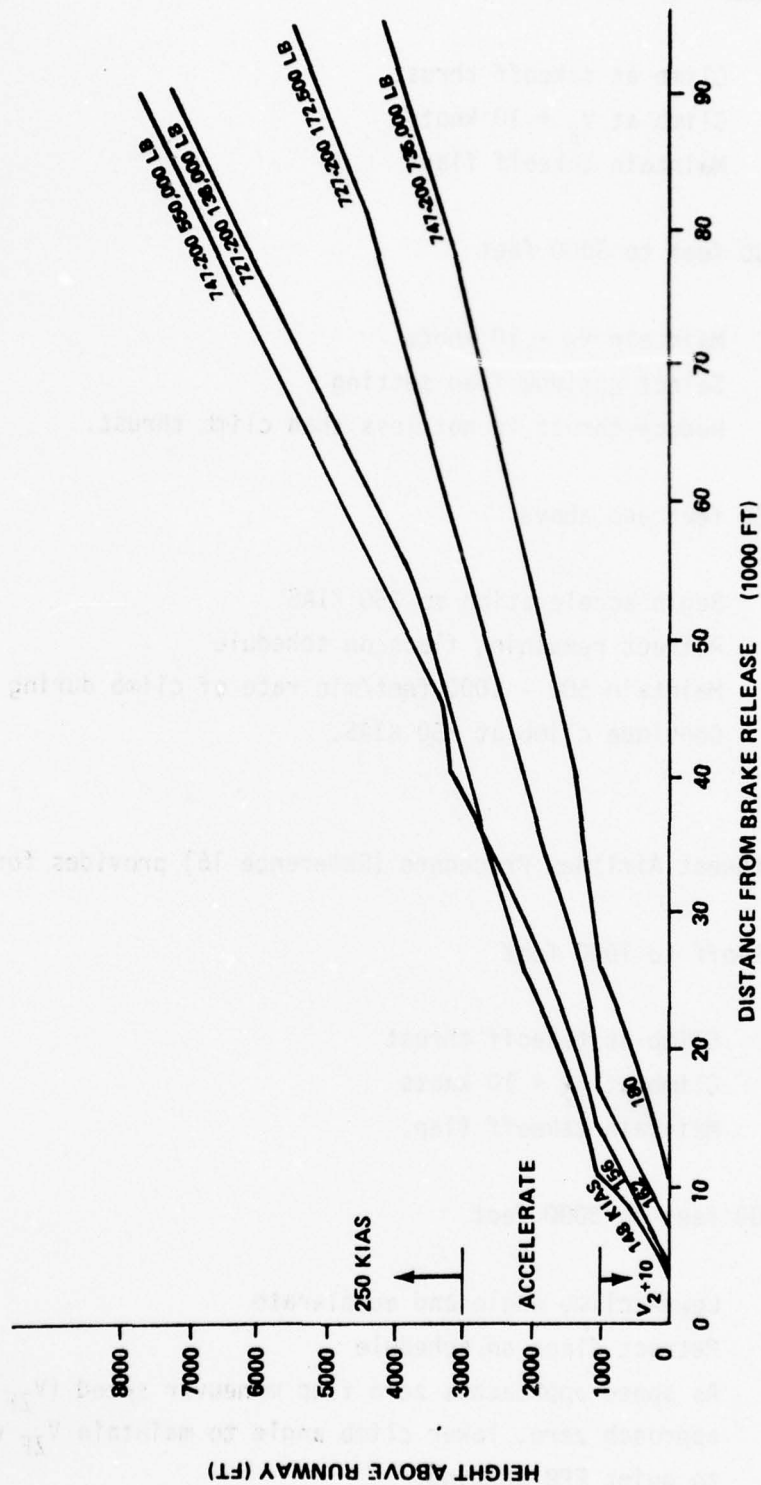


FIGURE 4.2.3-2 NORTHWEST AIRLINES NOISE ABATEMENT PROCEDURE

1) Takeoff to 1500 feet

- A) Climb at takeoff thrust
- B) Climb at $V_2 + 10$ knots
- C) Maintain takeoff flap.

2) 1500 feet to 3000 feet

- A) Maintain $V_2 + 10$ knots
- B) Select optimum flap setting
- C) Reduce thrust to not less than climb thrust.

3) 3000 feet and above

- A) Begin acceleration to 250 KIAS
- B) Retract remaining flaps on schedule
- C) Maintain 500 - 1000 feet/min rate of climb during acceleration
- D) Continue climb at 250 KIAS.

The Northwest Airlines Procedure (Reference 16) provides for:

1) Takeoff to 1000 feet

- A) Climb at takeoff thrust
- B) Climb at $V_2 + 10$ knots
- C) Maintain takeoff flap.

2) 1000 feet to 3000 feet

- A) Lower climb angle and accelerate
- B) Retract flaps on schedule
- C) As speed approaches zero flap maneuver speed (V_{ZF}) and flaps approach zero, lower climb angle to maintain V_{ZF} while reducing to quiet EPR setting.

D) Continue climb at or slightly above V_{ZF} .

3) 3000 feet and above

A) Apply climb thrust and accelerate to 250 KIAS

B) Continue climb to 250 KIAS.

Above 10,000 feet, the 250 KIAS speed limit is removed and the aircraft airspeed is adjusted to the climb to cruise condition the pilot selects considering airplane type and company procedures.

When a single departure track is used, the probability of conflict during the initial climb maneuvers due to reduced departure spacing may constrain the benefits achievable with CDTI departure spacing control. However, if parallel tracks are defined shortly after takeoff, the conflict potential will be low and the feasibility of using reduced departure separation greater.

It would appear that the CDTI departure separation control would be most successful when applied to that portion of the climbout after the preceding airplane has stabilized on a fixed climb to cruise condition (e.g., climb at fixed indicated airspeed). When, in-trail, aircraft are both climbing at the same constant indicated airspeed, separation is increasing due to the increase in groundspeed with altitude. However, depending upon the climb speed schedules and when each converts to constant Mach number, there may be separation reduction.

The problem with the earlier (initial climbout and noise abatement) portion of the departure profile is that the CDTI pilot does not know what to expect from the preceding flight. The ability of a CDTI pilot to maintain separation during various portions of the departure flight should be tested for feasibility and required departure spacing.

A negative aspect of a CDTI departure separation procedure in which the following aircraft maneuvers to maintain separation is that it by definition precludes resolving conflicts by adjusting the preceding airplane's flight profile.

This ties in with the recognition that before an aircraft is cleared for CDTI departure separation, it must be determined that this can be accomplished within the desirable climbout performance of the CDTI airplane. In addition, the direction (longitudinal, lateral or vertical) must be determined in which the CDTI airplane can and will maintain separation.

Assuming the CDTI airplane initially has safe separation, the fundamental conditions for successfully maintaining safe separation are one of the following:

- 1) The CDTI airplane will climb at the same or a lower indicated airspeed than the target airplane.
- 2) The CDTI airplane is above, will climb at the same speed or faster, and will level off above the target airplane.
- 3) The CDTI airplane is below, will climb at the same speed or slower and will level off below the target airplane.

4.2.3.4 Operational Concept

The following operational concept is recommended based on consideration of the departure separation task and available data.

4.2.3.4.1 Assumptions

The operational concept is based on the following assumptions:

- 1) The CDTI airplane will use relative traffic position as the basis for

flying the airplane to maintain safe separation.

- 2) ATC will monitor separation and retain ultimate responsibility for safe separation.
- 3) CDTI departure separation will be accomplished only by mutual agreement of ATC and the pilot.
- 4) ATC (in conjunction with the CDTI pilot as appropriate) will determine when CDTI departure separation can be used and the direction in which separation will be maintained.
- 5) ATC will provide the initial separation.

4.2.3.4.2 Generalized Concept

The generalized concept is for ATC to determine that the use of CDTI is desirable and plan the CDTI separation operation as to separation direction to be maintained and the limits of the operation.

The pilot will evaluate the request and if deemed flyable will accept the assignment. Then the pilot will use the CDTI display of his position relative to the target aircraft to fly the CDTI airplane to maintain safe separation.

CDTI departure separation will be discontinued when the CDTI aircraft reaches the limit of its clearance for this operation or upon prior direction of ATC. During CDTI departure separation, ATC will monitor the separation and should the separation go below a safe value or appear to be going below a safe value, ATC will intervene with instructions which will resolve the conflict.

4.2.3.4.2.1 Flow Diagram

Figure 4.2.3-3 is a flow diagram of the generalized departure separation control role. The following discussion relates to the functional diagram.

Air Traffic Control will initiate its use by identifying that departure separation is required and the use of CDTI to provide this separation will benefit either the airspace user or ATC.

The next step is for ATC to plan the CDTI departure separation function. To do this, ATC will determine in which direction(s) the CDTI airplane can maintain separation. The tests for feasible direction(s) would be the following:

Longitudinal Separation

Is the intended speed of the preceding aircraft equal to or greater than either the planned speed of CDTI aircraft or a speed to which the CDTI aircraft can reduce without significant penalty?

Lateral Separation

Is airspace available for a track parallel to the preceding aircraft's path? Will this parallel track lead to a situation insuring separation (e.g., leading to separate cruise altitudes)?

Vertical Separation

Is the CDTI airplane either:

- A) (1) above the preceding airplane by at least the prescribed minimum vertical separation distance?;

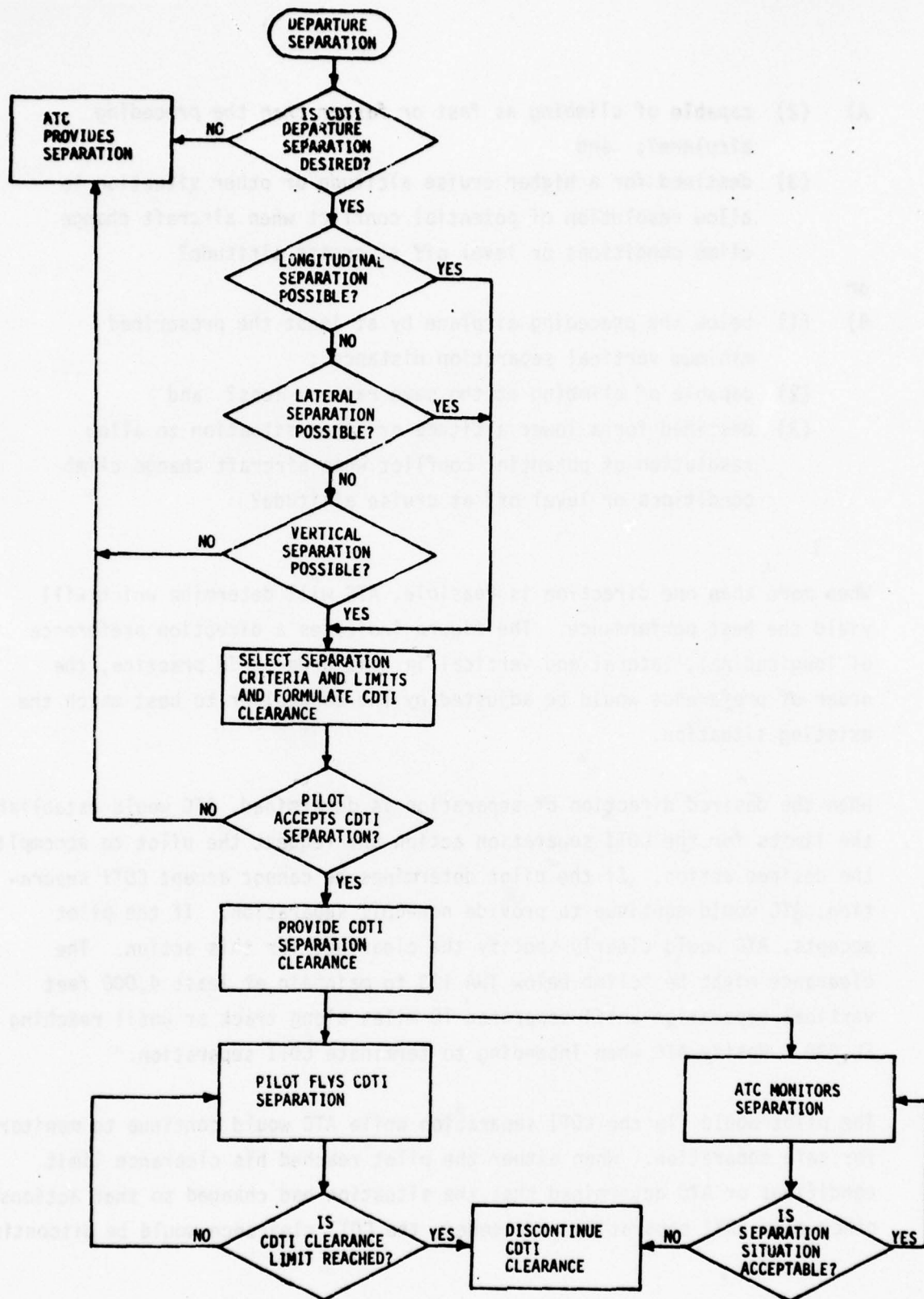


FIGURE 4.2.3 - 3 DEPARTURE SEPARATION FUNCTIONAL DIAGRAM

- A) (2) capable of climbing as fast or faster than the preceding airplane?; and
(3) destined for a higher cruise altitude or other situation to allow resolution of potential conflict when aircraft change climb conditions or level off at cruise altitude?

or

- B) (1) below the preceding airplane by at least the prescribed minimum vertical separation distance?;
(2) capable of climbing at the same rate or less? and
(3) destined for a lower altitude or other situation to allow resolution of potential conflict when aircraft change climb conditions or level off at cruise altitude?

When more than one direction is feasible, ATC will determine which will yield the best performance. The figure indicates a direction preference of longitudinal, lateral and vertical in that order. In practice, the order of preference would be adjusted by the controller to best match the existing situation.

When the desired direction of separation is determined, ATC would establish the limits for the CDTI separation action and request the pilot to accomplish the desired action. If the pilot determines he cannot accept CDTI separation, ATC would continue to provide non-CDTI separation. If the pilot accepts, ATC would clearly specify the clearance for this action. The clearance might be "climb below TWA 123 to maintain at least 4,000 feet vertical separation until separated 10 miles along track or until reaching FL 290. Notify ATC when intending to terminate CDTI separation."

The pilot would fly the CDTI separation while ATC would continue to monitor for safe separation. When either the pilot reached his clearance limit conditions or ATC determined that the situation had changed so that actions other than CDTI separation are needed, the CDTI clearance would be discontinued.

NOTE: The methods by which the functions in each block of Figure 4.2.3-3 are accomplished will depend upon further development of the CDTI system. For example, both the CDTI pilot and ATC are expected to participate in determining which separation directions are feasible and desirable; however, the extent and nature of their actions needs study to identify the best system considering both their capabilities and other duties.

4.2.3.4.2.2 Application Areas

CDTI departure separation is applicable to ATC operations where control is of one aircraft relative to another. This is today's method of operation.

In the future, departure operations may be based on predicting the trajectory of each flight, planning non-conflicting flight paths and releasing them with appropriate spacing. In such a system, CDTI departure separation could be employed when the actual flight path deviates enough from the predicted trajectory that a conflict may occur unless relative control is instituted.

CDTI departure separation can be used whenever:

- 1) safe separation exists initially;
- 2) the planned tracks and flight conditions of both CDTI and target airplane are non-varying or predictable;

- 3) the CDTI airplane can safely and efficiently maintain separation; and
- 4) it is the best way to handle the situation.

The duration of a CDTI departure separation can be as short or as long as it is helpful. Possibly very short clearances such as "CDTI maintain 4000 feet below TWA 123 for next 5 miles" may be very valuable.

Application of CDTI departure separation to situations in which the target airplane is changing its nominal speed or climb profile is questionable and would require considerable testing before use could be extended to these conditions.

CDTI departure separation should be used where it can increase system capacity by increasing the departure rate or reducing the controller workload.

4.2.3.4.2.3 Operating Procedures

The concept, at least for initial operations, is for ATC to request CDTI departure separation each time it is to be used.

4.2.3.5 System Requirements and Concept

The basic functional requirement is to provide guidance information for maintaining either longitudinal, lateral or vertical separation. The following paragraphs describe the performance requirements and display concept.

4.2.3.5.1 Performance Requirements

Assuming that guidance will be based on a display of the relative position of other traffic, the following are the estimated system performance

requirements. These values require verification and refinement by simulation and test.

Number of Targets - One (the assigned target aircraft).

Position Accuracy - Altitude data digitized in 100 foot increments and 1,000 foot accuracy in horizontal position.

Update Rate - 4 seconds

Coverage Volume (Displayed) - 5,000 feet in altitude, 10 miles laterally and longitudinally from ownship position.

Target Data - Basic target data is vertical and horizontal position. Additional data required, either supplied or derived on-board, are climb rate, velocity vector, and flight identity.

Guidance Data - Information which may be required to implement a satisfactory guidance capability may include: (1) ownship velocity vector, altitude, and climb rate; (2) altitude, longitudinal and lateral closing rates between ownship and target; and (3) computed climb rate or velocity vector for maintaining specified separation.

Guidance Accuracy - System should allow pilot to maintain separation to within 10 percent (one sigma) of the minimum separation standard (i.e., 100 feet for 1,000 foot vertical separation and 1,800 feet for 3 n.mi. horizontal separation).

4.2.3.5.2 Display

The display presents the target data and additional guidance information. The choice of system mechanization has direct implications on the data available for display.

A system using semi-active B-CAS for target relative position and not requiring an on-board area navigation system precludes ground speed or velocity vectors in either aircraft.

A system using ARTS-III and DABS as a data base could have ground speed or velocity vectors for both ownship and target.

A leader representing future position as a function of time requires velocity vector data.

The CDTI data is to be displayed on an EHSI in addition to other EHSI data pertinent to flying the aircraft.

The target aircraft must have identity data to insure that the correct target is being guided on. In addition, target altitude is useful or necessary in all cases.

The desirable guidance data are indications of:

- 1) current spacing relative to the minimum,
- 2) direction in which spacing is changing, and
- 3) rate at which spacing is changing.

Displays discussed here are examples to indicate required capabilities. It is expected that more optimum displays will be developed in preparing for simulation and flight tests.

Example displays are as follows:

Longitudinal Spacing

The basic display corresponding to a B-CAS with no RNAV equipment mechanization

would contain:

- 1) symbol showing relative target horizontal position (current separation) with target data block containing transponder code and altitude.
- 2) ownship symbol with leader in direction of travel and length equal to minimum distance separation.

Addition of ownship RNAV would allow ownship leader representing a time separation.

Addition of groundspeed vectors via ARTS-III/DABS would allow computation of relative speed in the longitudinal direction (along-track closing velocity).

Figure 4.2.3-4 shows an example display with an ownship leader indicating the minimum separation distance and an arrow which moves vertically relative to the target symbol and proportional to the along-track closing velocity (zero-closing velocity is indicated when arrow is directly opposite the target symbol).

Vertical Separation

If traffic data is to be added to an EHSI, the display is limited to a plan position. A separate CDTI display could show an elevation view.

A plan position display would be similar to the longitudinal separation display except the condition where CDTI and target aircraft are vertically aligned must be accommodated. One configuration is the material shown in parenthesis in Figure 4.2.3-4 consisting of a data block by the ownship symbol showing desired and actual vertical separation and the movement of the arrow relative to the target symbol proportional to current rate of change in vertical separation.

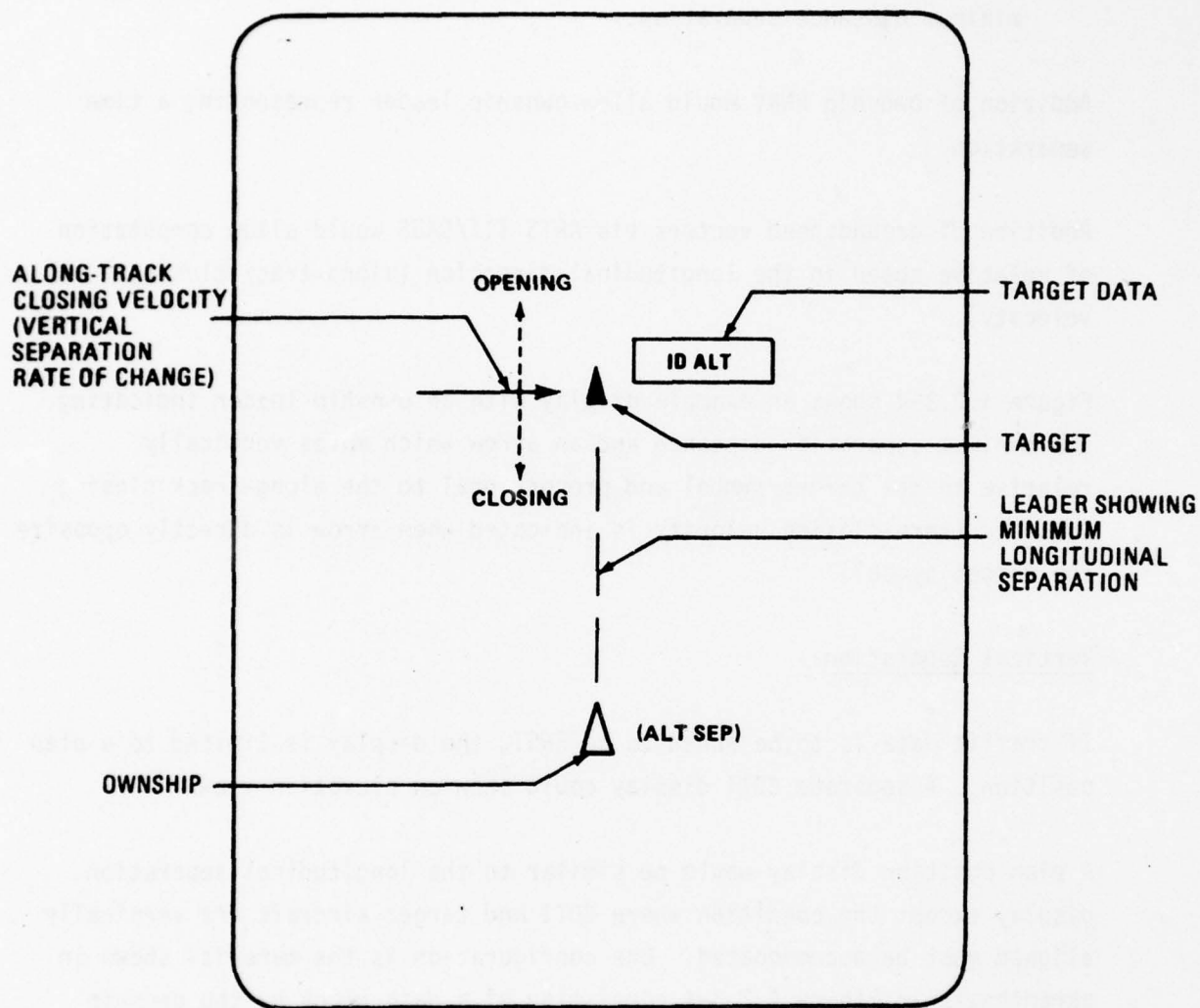


FIGURE 4.2.3-4 LONGITUDINAL SEPARATION (VERTICAL SEPARATION) DISPLAY

Lateral Separation

The display for maintaining lateral separation should show minimum lateral separation, current lateral separation and crosstrack component of closing velocity.

Figure 1.2-3 (in the Summary section) shows one possible arrangement, using a vertical bar alongside the target symbol to show the minimum separation distance and an arrow moving across scope relative to the target symbol and proportional to cross track closing velocity (zero closing velocity when arrow is directly below target aircraft symbol).

4.2.3.6 Potential Benefits

The principal benefits of CDTI departure separation are:

- 1) Increased runway capacity by relieving the controller of workload associated with vectoring aircraft to maintain safe separation, and by providing a means of more precisely controlling the separation of aircraft during climbout. This allows departures to be released with less separation while assuring that potential conflicts can be resolved, and
- 2) Reduced ATC operating costs due to reduced controller work force on a per operation basis.

Additional benefits which might develop are:

- 1) Reduced air-ground voice communications,
- 2) Reduced airspace requirements, and
- 3) Pilot acceptance of reduced separation standards.

4.2.3.7 Potential Problem Areas

The following are considered to be the problem areas which will identify analysis and testing needed to provide additional data as a basis for further evaluation.

Pilot

The increase in pilot workload and possible diversion of pilot's attention from critical flight instruments due to the CDTI guidance requirements may be a problem.

Operational

- 1) Use of CDTI separation may preclude the best available solution when this involves adjusting the flight of the preceding aircraft.
- 2) In actual traffic situation the opportunity to use CDTI separation may not often be present.
- 3) When using CDTI departures, the handover between sectors will involve pairs of aircraft (or chains) and the dependency between the flights. The next sector (controller and airspace) may have difficulty handling this situation.
- 4) Unexpected changes in the target aircraft's flight such as reactions to turbulence or convective cells may produce situations with which the CDTI airplane cannot cope.
- 5) When a controller is monitoring CDTI separations, a problem could occur if separation control suddenly reverts to the controller.
- 6) The assumption should be validated that CDTI separation is not feasible with reduced departure spacing during the initial portions of climbout where the speed and climb rates are varying significantly.

Design

- 1) The best (or an adequate) method of displaying and using relative position traffic data to fly and maintain separation must be developed.
- 2) Where two or more aircraft are involved in CDTI departure separation, there may be problems in either stability of the spacing or keeping the aircraft within the desirable performance boundary.
- 3) The guidance performance achievable for different displays as a function of system mechanization (i.e., B-CAS versus ARTS-III/DABS, on-board RNAV system) should be tested to determine the system data requirements.

Performance

A CDTI airplane may not be able to maintain separation within the required accuracy.

4.2.3.8 Test Scenario Considerations

Considerations in designing scenarios for simulation or flight tests include the following:

- 1) Departure traffic for investigating ATC operational problems should use a high-density departures-only runway with airline guide or actual observed traffic demand and aircraft type sequence.
- 2) The scenario should be complete for both pilot and controller workload; accounting for all tasks and actions the operators are loaded with while doing their basic job.

- 3) The scenario should include maximum workload situations for both pilot and controller.
- 4) Rare event occurrences should be programmed to investigate CDTI response and system recovery as to performance and safety.
- 5) Departure profiles should represent noise abatement and airspace constraints as required at major airports.

4.2.4 En Route Passing and Crossing

The En Route Passing and Crossing roles are those in which the pilot rather than the ATC controller has the responsibility for navigating to maintain the minimum prescribed safe separation; while accomplishing the co-altitude passing of another flight or crossing the path of another flight.

4.2.4.1 Problem Statement

Aircraft flying en route along the jet route structure must be controlled to maintain safe separations along track and at route intersections. When a faster aircraft overtakes a slower one along the same route, either the overtaking aircraft must be cleared to a new altitude, vectored around the slower aircraft, or slowed to a less desirable speed. The first two options place some workload on the controller and pilot. The third option imposes an operating penalty.

Figure 4.2.4-1 shows a histogram of observed en route operating speeds (true airspeeds) reported at towers during fiscal year 1969. Typical fuel-preferred cruise Mach for Boeing model aircraft are: .80 (707-320B), .72 (737-200), .80 (727-200), and .84 (747-100). This range of .12 Mach would translate into a 50 knot maximum velocity differential at 35,000 feet. With increased emphasis on fuel-efficient operations, there is an increasing requirement on ATC to provide desired altitudes and speeds.

1969 EN ROUTE IFR AIR TRAFFIC SURVEY

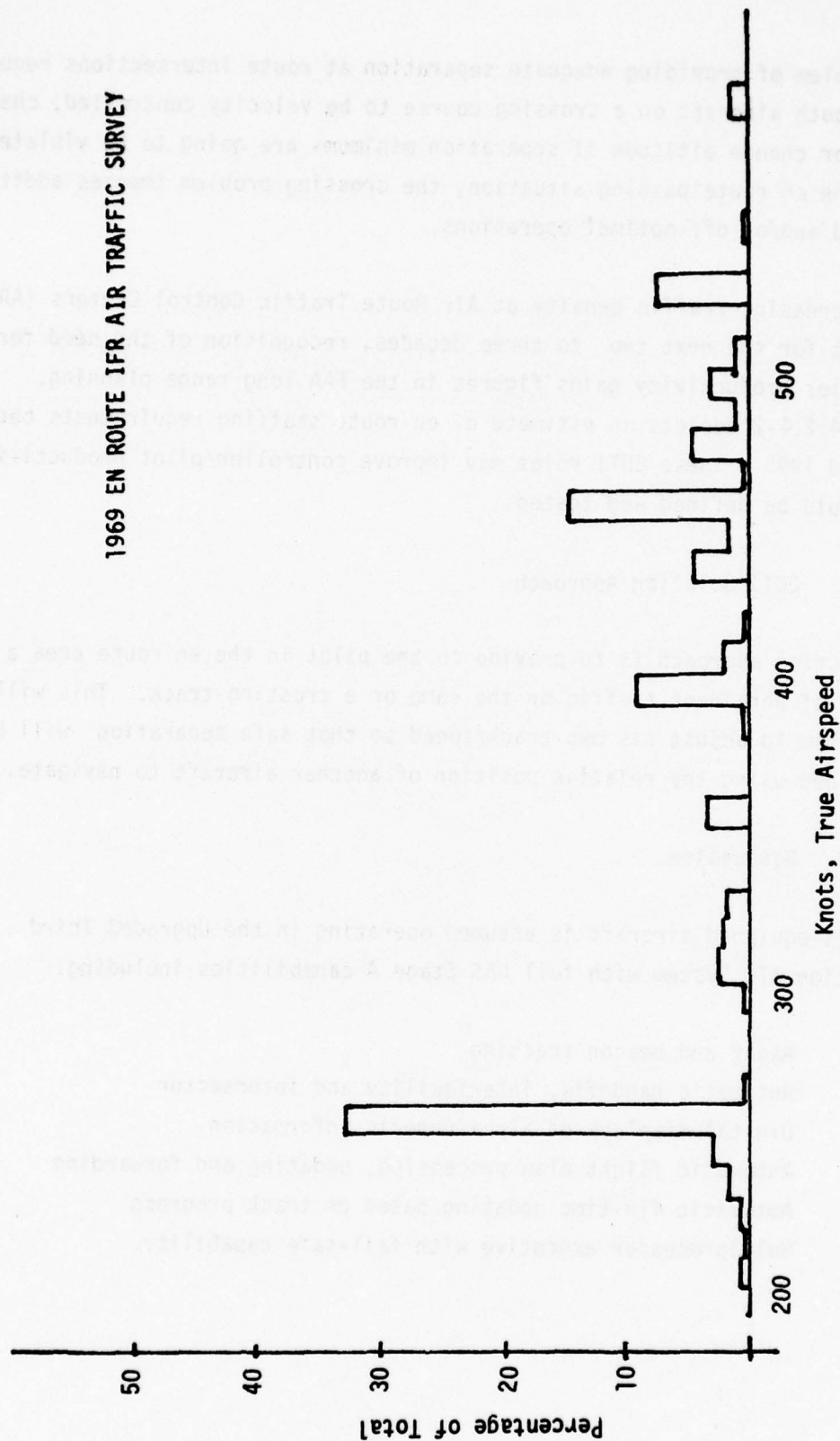


FIGURE 4.2.4-1 DISTRIBUTION OF AIR CARRIER EN ROUTE AIRSPEEDS

The problem of providing adequate separation at route intersections requires one or both aircraft on a crossing course to be velocity controlled, change course or change altitude if separation minimums are going to be violated. As in the en route passing situation, the crossing problem imposes additional workload and/or off-optimal operations.

With increasing traffic density at Air Route Traffic Control Centers (ARTCC's) forecast for the next two to three decades, recognition of the need for controller productivity gains figures in the FAA long range planning. Figure 4.2.4-2 depicts an estimate of en route staffing requirements between 1970 and 1995. These CDTI roles may improve controller/pilot productivity and should be defined and tested.

4.2.4.2 CDTI Solution Approach

The solution approach is to provide to the pilot in the en route area a display of pertinent traffic on the same or a crossing track. This will permit him to adjust his own track/speed so that safe separation will be maintained using the relative position of another aircraft to navigate.

4.2.4.3 Discussion

The CDTI-equipped aircraft is assumed operating in the Upgraded Third Generation ATC System with full NAS Stage A capabilities including:

- Radar and beacon tracking
- Automatic handoffs, interfacility and intersector
- Digital displays of alpha/numeric information
- Automatic flight plan processing, updating and forwarding
- Automatic fix-time updating based on track progress
- Multiprocessor executive with fail-safe capability.

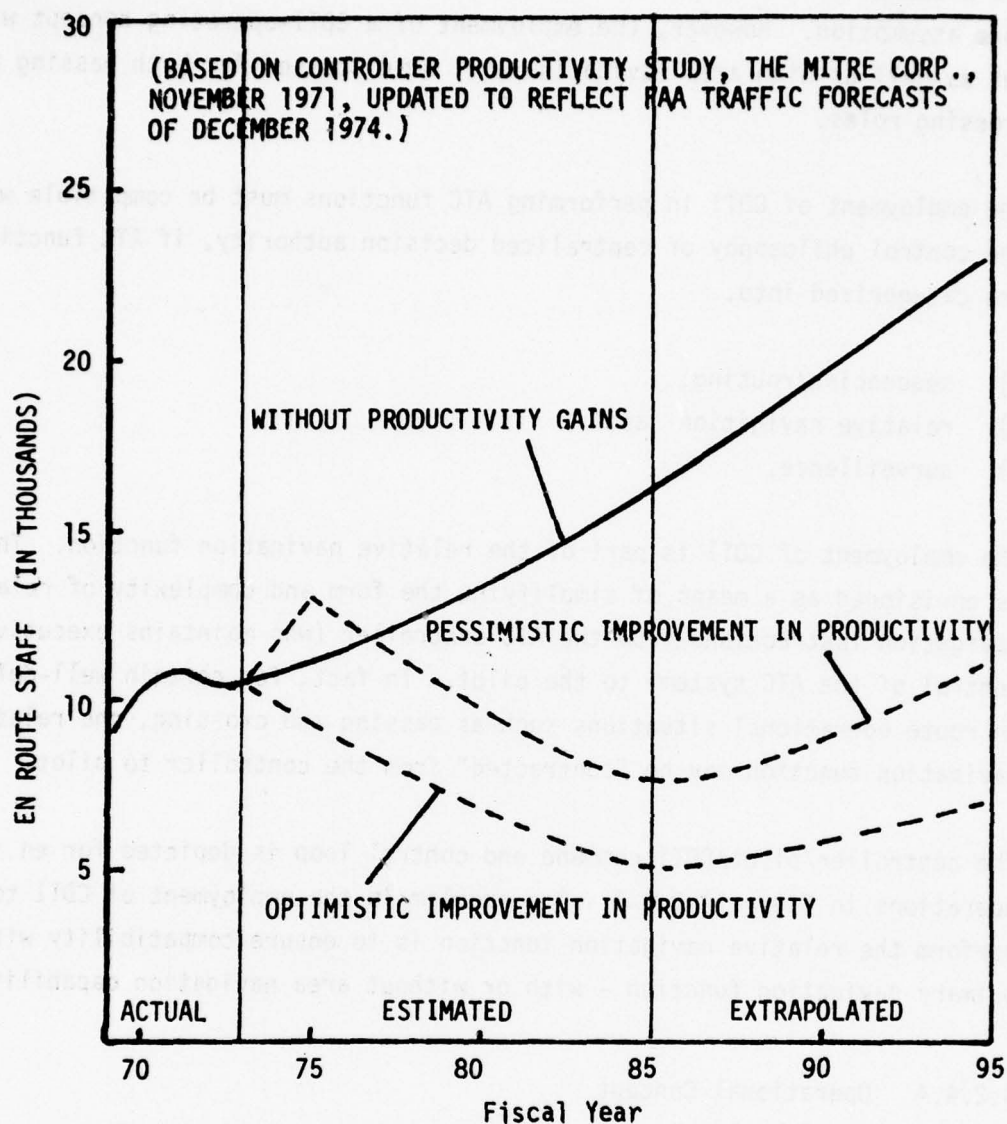


FIGURE 4.2.4-2 EN ROUTE STAFFING ESTIMATES

The presence of an area navigation capability in the cockpit seems a reasonable assumption. However, the employment of a CDTI-operating concept without as well as with area navigation will be discussed for both passing and crossing roles.

The employment of CDTI in performing ATC functions must be compatible with the control philosophy of centralized decision authority, if ATC functions are categorized into:

- 1) sequencing/routing,
- 2) relative navigation and
- 3) surveillance.

The employment of CDTI is part of the relative navigation function. The CDTI is envisioned as a means of simplifying the form and complexity of relative navigation instructions from the ATC controller (who maintains executive control of the ATC system) to the pilot. In fact, for certain well-defined en route operational situations such as passing and crossing, the relative navigation function may be "contracted" from the controller to pilot.

The controller/pilot/CDTI command and control loop is depicted for en route operations in Figure 4.2.4-3. One problem in the employment of CDTI to perform the relative navigation function is to ensure compatibility with the primary navigation function - with or without area navigation capability.

4.2.4.4 Operational Concept

The following operating concepts for the en route passing and crossing functions appear promising as CDTI application areas.

4.2.5.4.1 Assumptions

The operational concept is based on the following assumptions:

- 1) The ATC executive function will remain centralized.

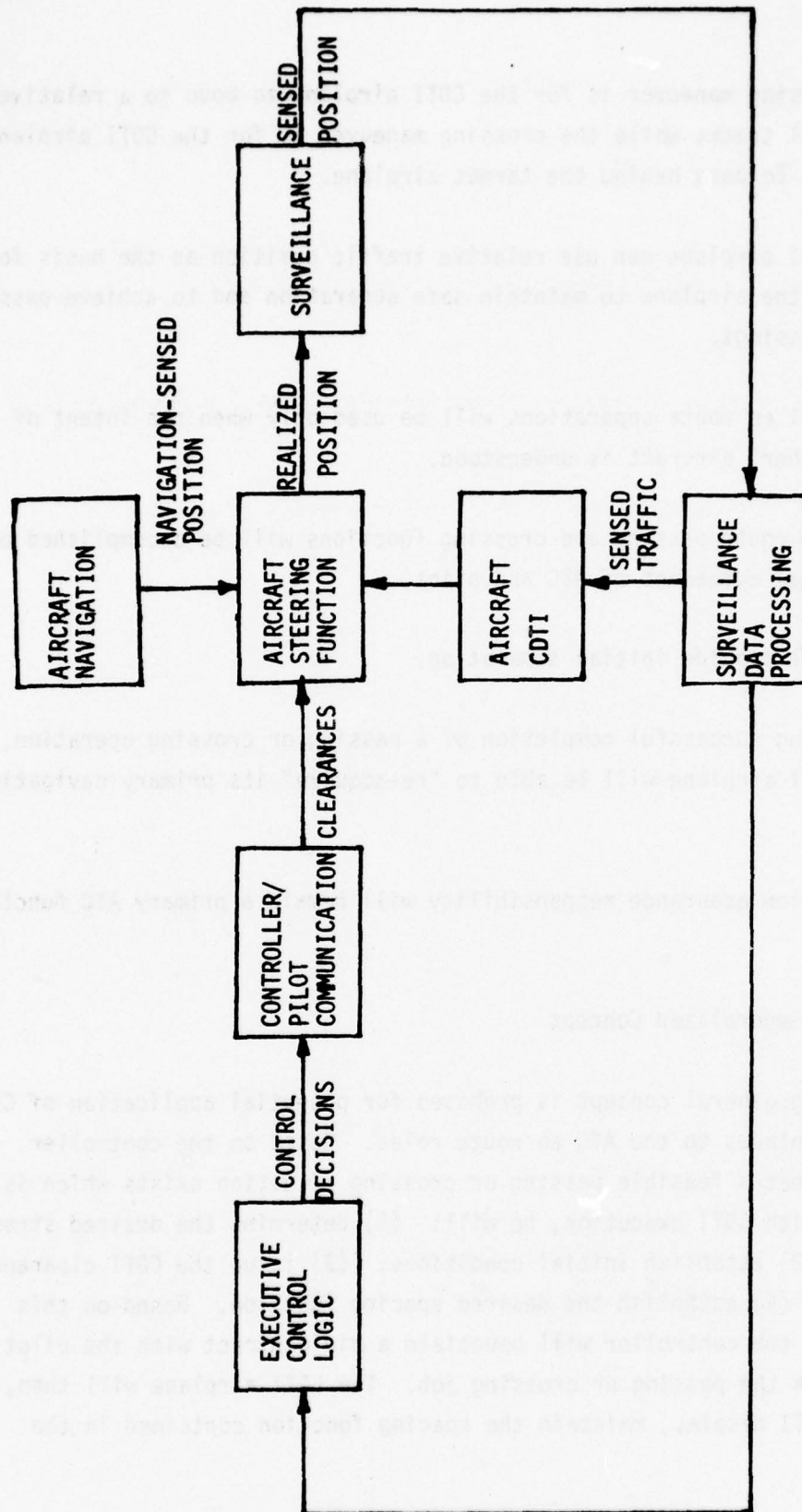


FIGURE 4.2.4-3 CONTROL LOGIC FUNCTIONAL FLOW

- 2) The passing maneuver is for the CDTI airplane to move to a relative parallel track; while the crossing maneuver is for the CDTI airplane to turn to pass behind the target airplane.
- 3) The CDTI airplane can use relative traffic position as the basis for flying the airplane to maintain safe separation and to achieve passing and crossings.
- 4) The CDTI en route separations will be used only when the intent of the "other" aircraft is understood.
- 5) CDTI en route passing and crossing functions will be accomplished only by mutual agreement of ATC and pilot.
- 6) ATC will provide initial separation.
- 7) Following successful completion of a passing or crossing operation, the CDTI airplane will be able to "re-acquire" its primary navigation mode.
- 8) Separation assurance responsibility will remain a primary ATC function.

4.2.4.4.2 Generalized Concept

The following general concept is proposed for potential application of CDTI-equipped airplanes to the ATC en route roles. Based on the controller assessment that a feasible passing or crossing situation exists which is compatible with CDTI execution, he will: (1) determine the desired stream speed(s); (2) establish initial conditions; (3) issue the CDTI clearance limits; and (4) establish the desired spacing function. Based on this information, the controller will negotiate a minicontract with the pilot to accomplish the passing or crossing job. The CDTI airplane will then, using the CDTI display, maintain the spacing function contained in the

clearance. The controller will continue in a monitor role intervening only in abnormal situations. Upon completion of the "minicontract", the pilot will return control to ATC for further action.

4.2.4.4.3 Flow Diagrams

Figures 4.2.4-4 and -5 typify the decision process and logic which might be employed by the controller/pilot system in utilizing the CDTI to perform passing and crossing functions in the en route system.

4.2.4.4.4 Application Areas

CDTI en route passing and crossing operations are applicable to those ATC situations where (1) two aircraft are interacting in a predictable fashion; (2) control mechanization can be relative to the other aircraft (not time-based); and (3) the control aircraft (the aircraft made responsible for maintaining separation) is appropriately equipped.

4.2.4.4.5 Operating Procedures

The concept involves three phases:

- 1) Initiation, where ATC guarantees separation and negotiates a contract with the CDTI aircraft;
- 2) Execution, during which navigation to provide separation is the primary responsibility of the CDTI aircraft; and
- 3) Termination, with resumption of usual separation responsibilities.

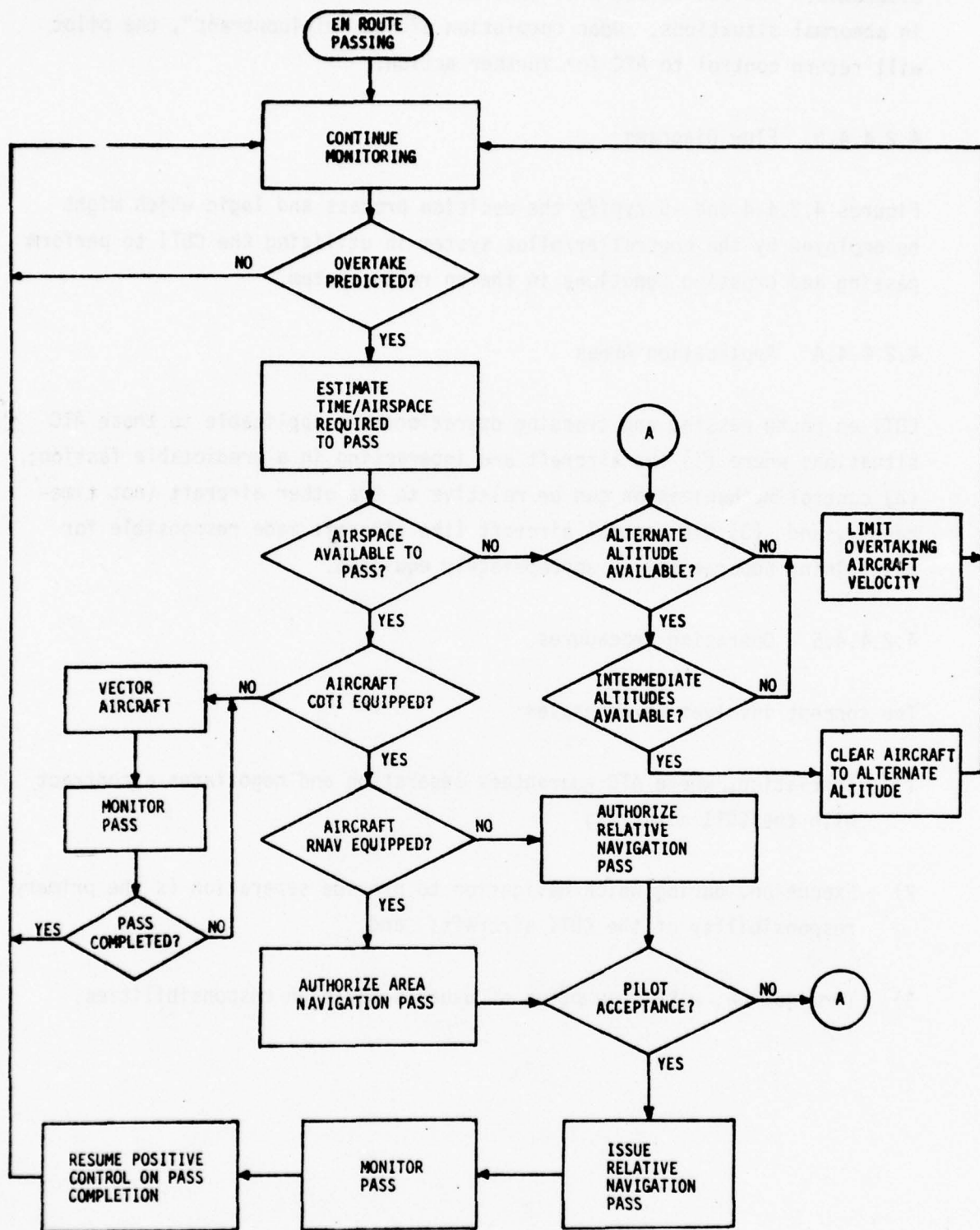


FIGURE 4.2.4 - 4 EN ROUTE CONTROL PASSING LOGIC

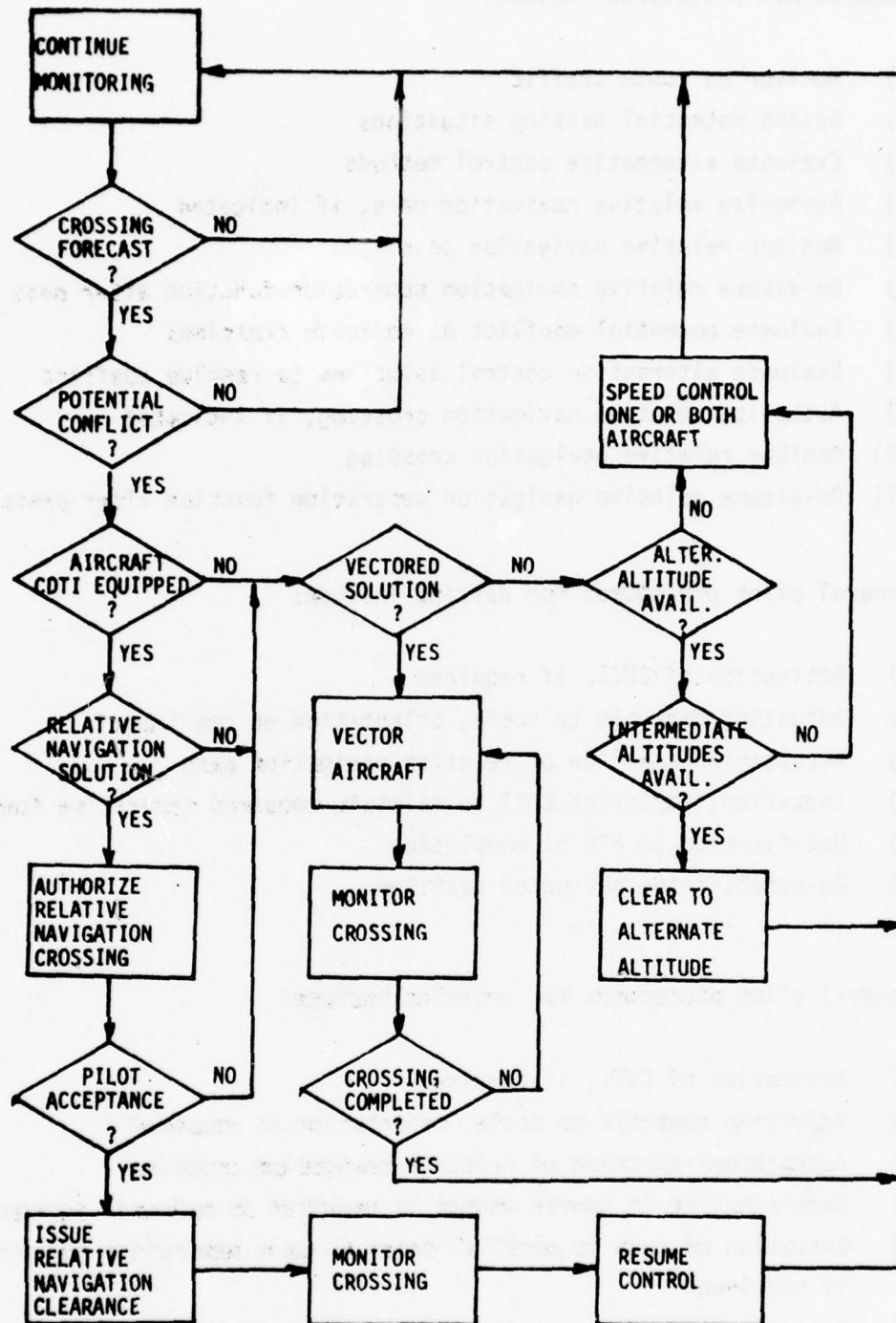


FIGURE 4.2.4-5 EN ROUTE CONTROL CROSSING LOGIC FLOW

General ATC procedures include:

- 1) Monitor en route traffic
- 2) Assess potential passing situations
- 3) Evaluate alternative control methods
- 4) Authorize relative navigation pass, if indicated
- 5) Monitor relative navigation pass
- 6) Re-assume relative navigation separation function after pass
- 7) Evaluate potential conflict at en route crossings
- 8) Evaluate alternative control solutions to resolve conflict
- 9) Authorize relative navigation crossing, if indicated
- 10) Monitor relative navigation crossing
- 11) Re-assume relative navigation separation function after crossing.

General pilot procedures for passing include:

- 1) Activation of CDTI, if required
- 2) Adjusting controls to scale, orientation as required
- 3) Acceptance/rejection of relative navigation pass
- 4) Execution, employing CDTI to maintain required separation function
- 5) Notification to ATC of completion
- 6) Re-establishing navigated position.

General pilot procedures for crossing include:

- 1) Activation of CDTI, if required
- 2) Adjusting controls to scale, orientation as required
- 3) Acceptance/rejection of relative navigation crossing
- 4) Determination if course change is required to maintain separation
- 5) Execution of turn to parallel track to gain separation for crossing, if required
- 6) Execution of crossing using CDTI to maintain required separation function
- 7) Notification to ATC of cross completion
- 8) Re-establish navigation position.

4.2.4.5 System Requirements and Concept

The basic functional requirements of the en route CDTI roles are: (1) provide relative navigation/guidance information; (2) provide a separation monitor; and (3) provide transition from the fixed navigation system (and back).

The following discussion of system requirements is divided into performance and display considerations.

4.2.4.5.1 Performance Requirements

One limitation in use of the CDTI concept for en route passing is the substantial distance required to affect a pass for the relatively small velocity differentials likely to be encountered. Figure 4.2.4-6 illustrates a passing geometry. When the overtaking aircraft reaches a critical distance, d_{crit} , behind the slower aircraft and a CDTI clearance is obtained, the passing aircraft is assumed to initiate a turn with radius of curvature R_c . The passing aircraft will move into a parallel track at distance d_p offset from the primary track. After the pass the faster aircraft will move in front of the slower aircraft with distance separation d_{crit} again provided.

For such an assumed geometry, the time required to pass is given by

$$t = (4 R_c \gamma + 2 d_{crit} - 4 R_c \sin \gamma) / \Delta v$$

where

$$\gamma = \cos^{-1} \frac{2 R_c - d_p}{2 R_c} \text{ (radians)}$$

R_c = radius of curvature of the turn (n.mi.)

d_p = lateral separation required (n.mi.)

d_{crit} = along track separation (n.mi.)

Δv = velocity differential (knots)

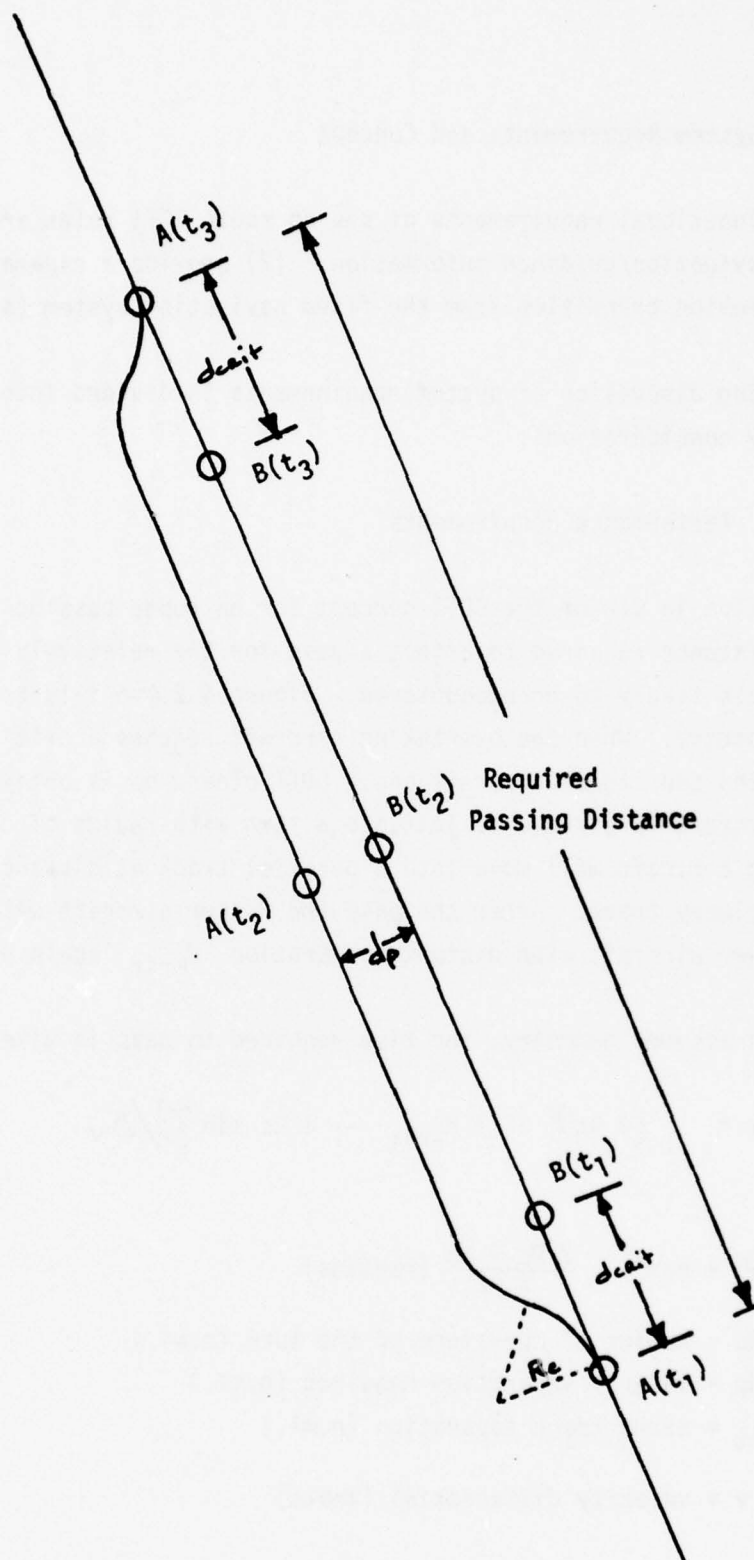


FIGURE 4.2.4-6 TYPICAL PASSING GEOMETRY

Then the along track distance required is

$$d = V_1 t + 2 d_{crit}$$

where V_1 = slower aircraft velocity (knots).

Assuming a 15° bank angle at en route cruise speed, Figure 4.2.4-7 translates various bank angles into radii of curvature. For a 10 n.mi. longitudinal separation and a 4 n.mi. lateral separation, Figure 4.2.4-8 summarizes the longitudinal overtake distance required for the pass. As indicated in the problem statement, Paragraph 4.2.4.1, an expected velocity differential of 25 to 30 knots would translate into a requirement for 300 to 350 n.mi. to pass. Considering that the average stage length today is slightly over 1 hour and about 400 n.mi., the frequency with which an en route pass could be completed would seem to be small.

For the en route crossing role of CDTI, guidance strategy must be developed to allow an aircraft to cross behind a second aircraft at a safe distance separation. In Figure 4.2.4-9, if aircraft B crosses behind aircraft A continuing on his initial course, the minimum distance separation d_{min} will be less than the required d_{crit} . Therefore, aircraft B must initiate a standard maneuver to provide:

- 1) a safe crossing distance behind A, and
- 2) minimum deviation from B's desired course.

One such possible maneuver is illustrated by the dashed path.

Assuming that guidance will be based on a display of the relative position of other traffic, the following are the estimated system performance requirements.

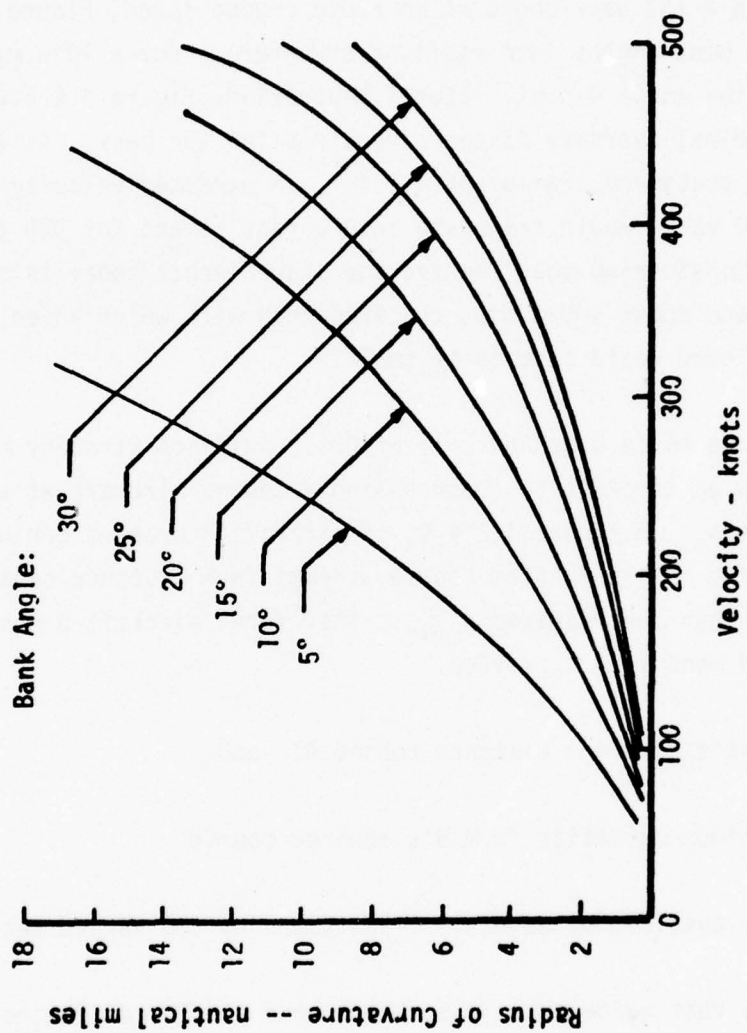


FIGURE 4.2.4-7 RADIUS OF CURVATURE VERSUS BANK ANGLE

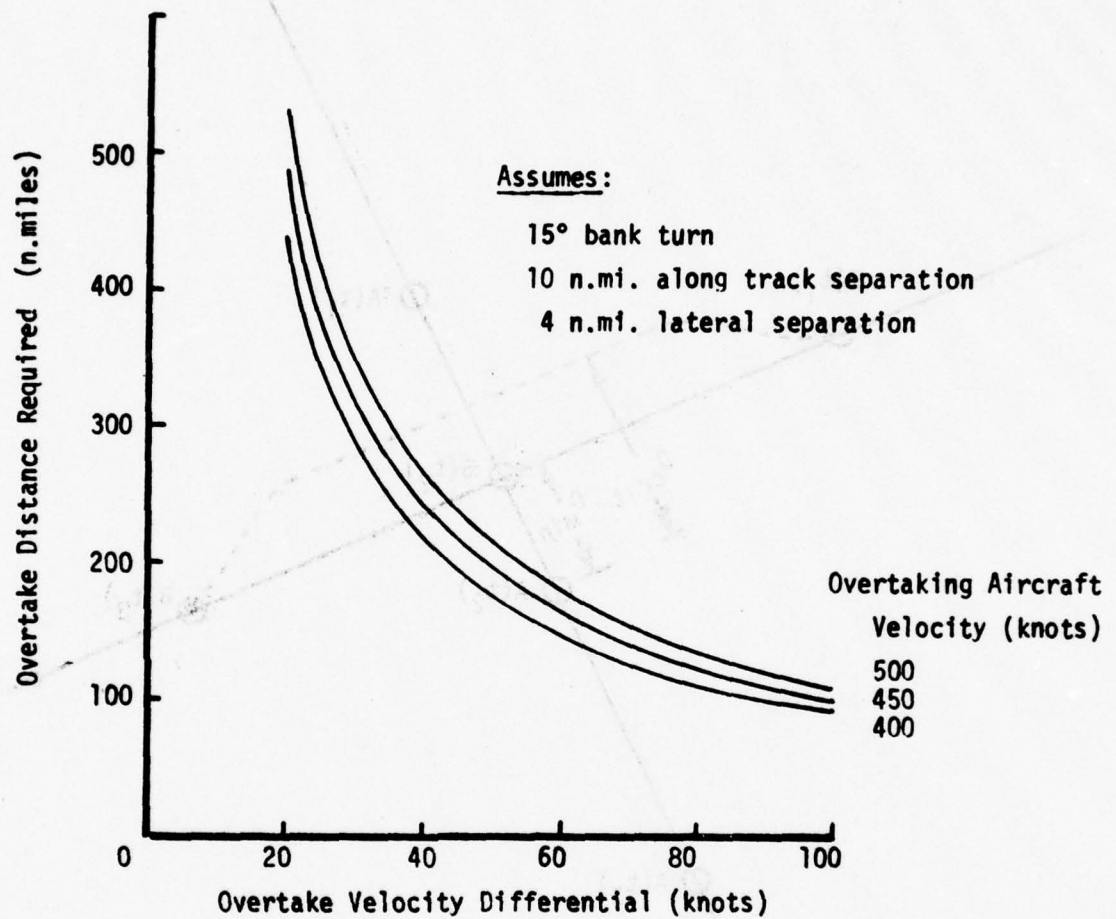


FIGURE 4.2.4-8 REQUIRED PASSING DISTANCE

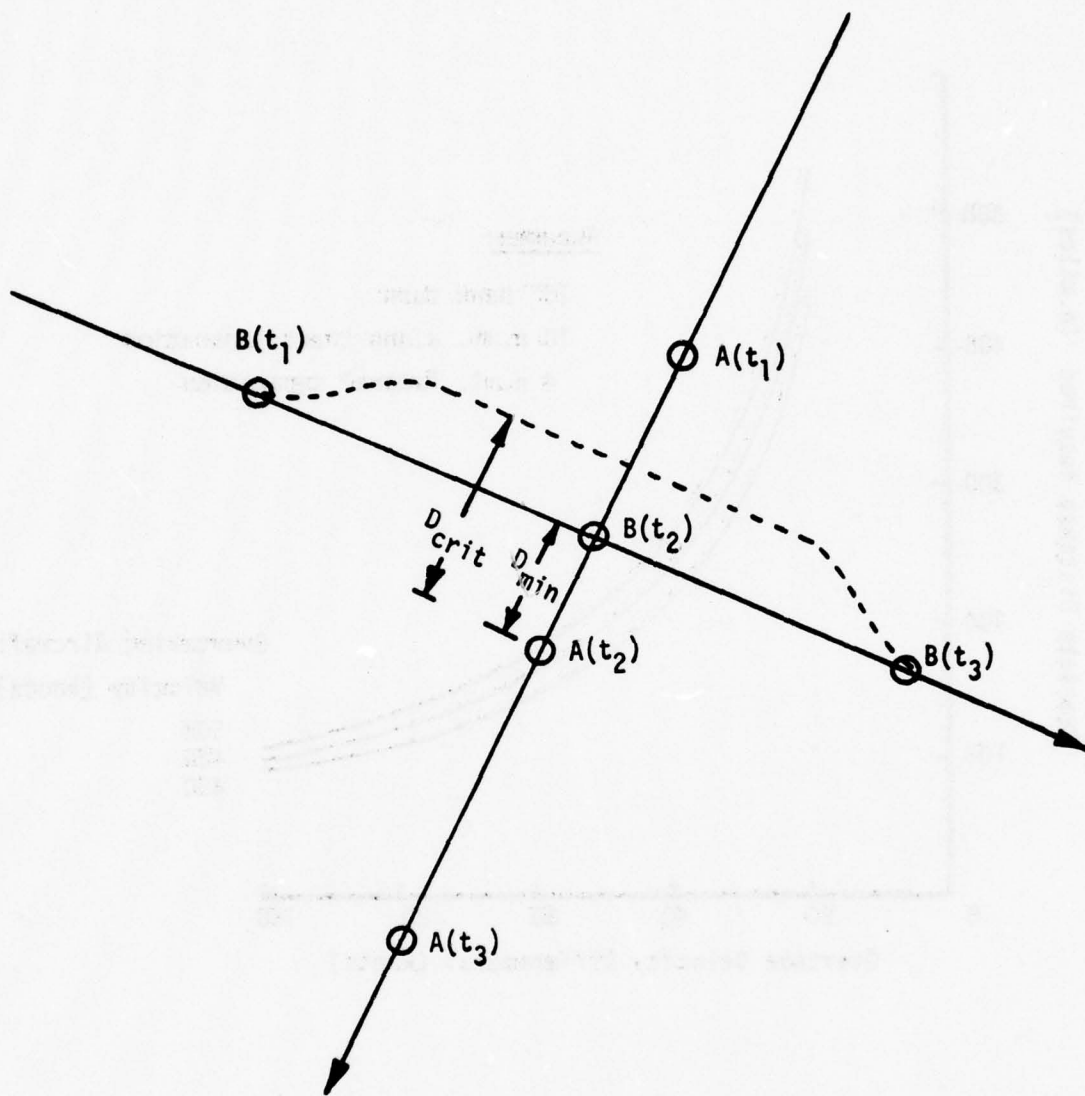


FIGURE 4.2.4 - 9 EN ROUTE CROSSING MANEUVER

These values require verification and refinement by simulation and test.

Number of Targets - One (the assigned target aircraft)

Position Accuracy - Altitude data digitized in 100 foot increments and 3,000 foot accuracy in horizontal position.

Update Rate - 12 seconds

Coverage Volume (Displayed) - 5,000 feet in altitude, 20 miles laterally and longitudinally from ownship position.

Target Data - Basic target data is vertical and horizontal position. Additional data required, either supplied or derived on-board, is turn rate, velocity vector, and flight identity.

Guidance Data - Information which may be required to implement a satisfactory guidance capability may include: (1) ownship velocity vector and altitude; (2) altitude, longitudinal and lateral closing rates between ownship and target; and (3) computed velocity vector for maintaining specified separation.

Guidance Accuracy - System should allow pilot to maintain separation to within 10 percent (one sigma) of the minimum separation standard (i.e., 6,000 feet for 10 n.mi. horizontal separation).

4.2.4.5.2 Displays

The display presents the target data and additional guidance information. The choice of system mechanization has direct implications on the data available for display.

The desirable guidance data are indications of:

- 1) current spacing relative to the minimum,
- 2) direction in which spacing is changing, and
- 3) rate at which spacing is changing.

The development of an en route display requires consideration of compatibility of use with terminal area CDTI applications. As the coverage volume and resolution requirements en route will be substantially different from terminal area requirements design considerations of scale change (selection) must be critical to en route use of CDTI.

Also, the presence or absence of an on-board area navigation capability must impact the display requirements. Uses of CDTI with an on-board area navigation system may be significantly different from uses envisioned without such a capability. The corresponding display requirements may change accordingly.

4.2.4.6 Potential Benefits

Potential benefits of the use of CDTI in performing en route passing and crossing functions include:

- 1) Reduction in controller workload;
- 2) Reduction in air-ground voice communications load;
- 3) Pilot acceptance of reduced en route separation minimums due to tighter control-loop; and
- 4) More efficient en route flight operations due to increased passing and crossing capacities.

4.2.4.7 Potential Problem Areas

The following problem areas have been identified associated with the application of CDTI to en route passing and crossing roles. These areas provide identification of analysis and testing needed to provide additional data in order to better evaluate the proposed CDTI uses. The problem areas are divided into pilot, operational, design, and performance considerations.

Pilot

- 1) The increase in pilot workload and possible diversion of pilot's attention from flight instruments due to the CDTI guidance requirements may be a problem.
- 2) The use of relative navigation in passing or crossing may increase the conventional navigation workload in the absence of an area navigation system.
- 3) For en route crossing where a separation maneuver is required, the pilot must be able to determine the required path.

Operational

- 1) Use of CDTI separation may preclude the best available solution when this involves adjusting the flight of the preceding aircraft.
- 2) Unexpected changes in the target aircraft's flight such as reactions to turbulence or convective cells may produce situations with which the CDTI airplane cannot cope.
- 3) When a controller is monitoring CDTI separations, management of the situation may be a problem if separation control suddenly reverts to the controller.

- 4) Use of CDTI has been assumed in a two airplane environment. Problems are introduced in passing or crossing situations with a third, fourth, airplane.
- 5) If the "target" airplane is also CDTI-equipped, it may unilaterally respond to the traffic situation and develop an unstable control situation.
- 6) When CDTI maneuvers extend across sector boundaries, this may cause traffic control problems in the downstream sectors.

Design

- 1) The best (or an adequate) method of displaying and using relative position traffic data to fly and maintain separation must be developed. Solutions developed with an on-board area navigation system will be different from those developed without such a capability.
- 2) The guidance performance achievable for different displays as a function of system mechanization should be tested to determine the system data requirements.

Performance

- 1) The capability of a CDTI airplane to maintain separation within the required accuracy may be a problem.
- 2) The display update rate should be analyzed to determine sufficiency. While en route radar update rate is sufficient for the controller, there may be significant differences in the pilot's requirements for CDTI relative navigation.

4.2.4.8 Test Scenario Considerations

Considerations in designing scenarios for simulation or flight tests include the following:

- 1) En route traffic for investigating ATC operational problems should use a high-density route structure with scheduled or actual observed traffic demand and aircraft type sequence.
- 2) The scenario should be complete for both pilot and controller workload; accounting for all tasks and actions the operators are loaded with while doing their basic job.
- 3) The scenario should include maximum workload situations for both pilot and controller.
- 4) Rare event occurrences should be programmed to investigate CDTI response and system recovery as to performance and safety.
- 5) En route passing and crossing CDTI roles should be evaluated both with and without on-board area navigation capability.
- 6) Situation geometries should be varied to represent the complete spectrum expected from operational situations.

4.2.5 Separation During Severe-Weather Avoidance

CDTI separation during severe-weather avoidance is the role in which the pilot rather than the ATC controller has the responsibility for navigating (selecting a path) to maintain the minimum prescribed safe separation from other traffic while avoiding areas of severe weather (primarily turbulence due to convective activity).

4.2.5.1 Problem Statement

When aircraft encounter thunderstorms along their route of flight, a special problem arises in that they must avoid the cells where severe turbulence can injure passengers and damage or destroy the aircraft. Usually the path to avoid cells of severe turbulence is circuitous and continuously subject to reassessment and change. If other aircraft are in the area, the need to select paths which provide safe separation also exists. These two criteria for selection of a safe path can be in conflict.

One solution is to route the flight completely around the area of severe weather. However, in arriving or departing a terminal area, this is often not possible and the area must be penetrated (having surveyed the situation and determined that the aircraft can find a safe path through the area).

The pilot has visibility of the weather ahead out the windshield and from a weather radar which detects the cells where severe turbulence exists. On the other hand, the controller has information on all flights in the area, but no fine-grain information on the location of individual weather cells.

Today, the controller routes flights through or around areas of severe weather based on weather bureau and pilot reports. When the controller is not aware of the safe path, the pilot requests permission to deviate to a path he determines is safe. The controller negotiates this deviation with the pilot while also solving potential conflicts which the deviation might cause.

In terminal areas where traffic is dense and the pilot is busy, it is often necessary to use flight constraints such as holding, reduced flow rate, and deviations to define paths for all flights which are safe both from turbulence and conflict.

Less than optimum operations occur because the controller has the traffic on his radar, but not the weather cells (at the flight altitude); while the

pilot has the weather cells at his altitude on his radar, but not the other traffic. The solution is to get all the relevant data at one location where a decision can be made considering the total situation.

4.2.5.2 Solution Approach

The CDTI solution is to provide traffic data on the same airborne display as the severe weather data and allow the pilot to select a path and navigate to avoid both conflict with other flights and the severe weather cells.

4.2.5.3 Discussion

Underlying the operational concept for this role is the knowledge that if an aircraft is entering an area of severe weather it will in any case divert around the cells. Thus, adding CDTI only means that the pilot will be aware of other traffic and can select a safe path which is also less likely to produce a conflict.

The general concept is for ATC to release the pilot to pick his way through an area of severe weather and then return to his original flight path. If one pilot needs to do this, it can be assumed that other pilots in the area will be doing the same thing. The question then arises as to how a pilot uses the CDTI to avoid both severe weather and conflicts with other traffic, when the other traffic's path is not predictable. Without constraints this would be a pure "distributed management system" in which no one knew the others intent. This may not be a workable system and the first task is to develop constraints (such as clearance limits and special instructions) so that a feasible concept can be envisioned.

A feasible system might be where ATC would authorize CDTI severe-weather separation when it has been determined that the CDTI aircraft can fly to avoid conflict with another aircraft and this is specified in the CDTI clearance. For example, "UA 567 cleared to divert through severe weather, maintain separation from TWA 123, return to original track as soon as

practical prior to reaching Barnefield intersection". Further clearance refinements such as direction and maximum lateral extent of diversion could be used, based on pilot/controller conferencing. For example, if the CDTI and other traffic are arrivals with a planned sequence, the CDTI would be cleared to maintain separation ahead or behind according to sequence number.

The most value from this CDTI role may come from cases where the pilot is authorized to pick his way through weather and the availability of data on other traffic encourages him to select a path which also avoids conflicts. This could work where the nominal CDTI track has been planned by ATC to be clear of conflicts and therefore if the pilot does not wander too far, the probability of conflict is low.

When the CDTI airplane cannot readily maintain lateral/longitudinal separation from other traffic, it can be cleared to change altitude, or adjust rate of change of altitude.

When CDTI clearances are communicated, other proximate aircraft should be made aware of the intended operation as they may be involved. In fact, air to air coordination between aircraft picking their way through weather may be desirable so flights could know each others intent and cooperate. The practicability of this is not known.

The situation that may make CDTI severe-weather avoidance practical is that the traffic initially is not random; since ATC has it organized along routes. Therefore, conflicts will not be a normal result of weather diversion maneuver and in most cases will be easy to avoid.

The objective of the separation operation in the severe weather avoidance role is only to insure that separation doesn't degrade to where a conflict occurs. This differs from the arrival in-trail spacing and departure separation roles in which the separation objective is effectively to maintain some position relative (fixed separation) to the target airplane. Also severe weather avoidance involves insuring separation from one or more airplanes. As a result, the CDTI guidance task and display information for severe weather avoidance are somewhat different. In effect, the other traffic become additional moving cells to be avoided.

4.2.5.4 Operational Concept

The following recommended operational concept has been developed, based on analysis of the operational problem and available CDTI data.

4.2.5.4.1 Assumptions

The following assumptions form the basis for the operational concept.

- 1) CDTI severe weather avoidance separation clearances would be provided for individual situations.
- 2) Prior to granting clearance, ATC will determine that the CDTI aircraft can successfully avoid other traffic while avoiding weather.
- 3) ATC will continue to monitor separation and take action to resolve conflicts should separation deteriorate so a conflict becomes imminent.
- 4) When proximate aircraft both have CDTI, they will be informed of any CDTI clearances.
- 5) The CDTI severe weather avoidance separation clearance will specify traffic to be avoided and the direction (method) for achieving the separation.

4.2.5.4.2 Generalized Concept

The generalized concept is for the pilot to determine that CDTI severe weather avoidance separation is desired and request it from ATC.

ATC will determine the specific nature of the clearance and clearance limits. The pilot will fly the CDTI clearance until past the weather and back on track or until ATC changes the clearance.

4.2.5.4.2.1 Flow Diagram

Figure 4.2.5-1 is a flow diagram of the generalized severe weather avoidance separation role. The following discussion relates to this functional diagram.

The pilot would assess the weather ahead both visually and with the weather radar. When he detects severe weather in his path which he must go around or pick his way through, he would ask the controller for a CDTI severe weather avoidance clearance. He may indicate the direction he plans to go, in diverting from his assigned path.

Upon receipt of the request, ATC would review the traffic situation and identify any other flights which may be objects of a potential conflict. ATC would plan in general how the pilot could avoid weather and maintain separation from the other flight(s). This could determine that the CDTI pilot should plan on following (or leading) the other flight, maintain lateral separation or change altitude (if a conflict develops).

Considering the extent of the weather (possibly based on pilot-provided information) and the future path of the flight, the limits of the clearance would be determined. The limit being the point by which the CDTI pilot should return to his original flight track (or possibly a new assigned track). The limit could be a fixed distance, prior to reaching some traffic-significant point along the route (e.g., an intersection) or upon passing the area of severe weather.

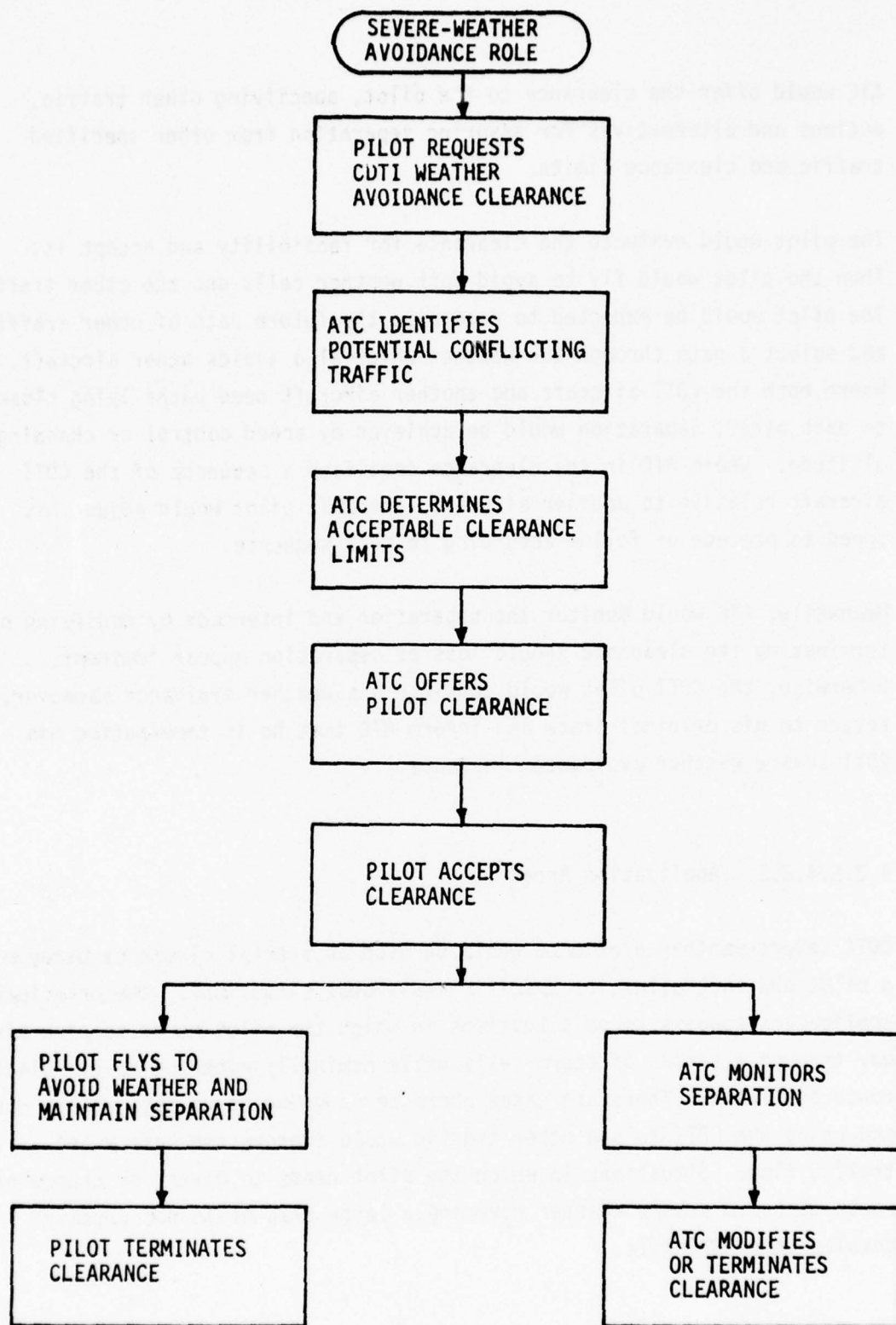


FIGURE 4.2.5 - 1 SEVERE-WEATHER AVOIDANCE FUNCTIONAL DIAGRAM

ATC would offer the clearance to the pilot, specifying other traffic, actions and alternatives for assuring separation from other specified traffic and clearance limits.

The pilot would evaluate the clearance for feasibility and accept it. Then the pilot would fly to avoid both weather cells and the other traffic. The pilot would be expected to recognize the future path of other traffic and select a path through the weather which also avoids other aircraft. Where both the CDTI aircraft and another aircraft need paths lying close to each other, separation would be achieved by speed control or changing altitude. Where ATC in the clearance specified a sequence of the CDTI aircraft relative to another aircraft, the CDTI pilot would adjust his speed to precede or follow according to this sequence.

Meanwhile, ATC would monitor the separation and intercede by modifying or terminating the clearance should loss of separation appear imminent. Otherwise, the CDTI pilot would complete his weather avoidance maneuver, return to his original track and inform ATC that he is terminating his CDTI severe weather avoidance clearance.

4.2.5.4.2.2 Application Areas

CDTI severe-weather avoidance would be used as special clearance between a pilot and controller for specific individual situations. The principal application appears to be situations in which the pilot needs to pick his way through a series of storm cells while nominally adhering to his cleared route of flight. There are cases where he is going to do this in any case and using the CDTI to see other traffic would improve the safety and traffic flow. Situations in which the pilot needs to divert or change his route to avoid severe weather covering a large area would not usually involve this CDTI role.

The pertinent type of situation often occurs during low altitude cruise, climb-out and let-down. Areas of severe weather cannot be expected to adhere to the boundaries of the terminal area and may often involve both en route and terminal area control. This means ATC handoffs may often occur during the CDTI severe weather avoidance, and both terminal area and en route facilities should be mechanized to support this CDTI role.

4.2.5.4.2.3 Operating Procedures

Pilot Procedures

General pilot procedures include:

- 1) Activation of the system when severe weather avoidance is anticipated.
- 2) Adjusting controls to obtain pertinent data on the EHSI.
- 3) Obtaining a CDTI severe weather avoidance clearance.
- 4) Assessing the speed and path considerations necessary to provide safe separation from both the severe weather and any pertinent traffic.
- 5) Comparison with ATC provided maneuvering limits for acceptability.
- 6) Controlling his own airplane to maintain the required separation function.

ATC Procedures

General ATC procedures include:

- 1) Activate each participating flight into the CDTI severe weather avoidance with self-separation role as it enters an area of severe weather (when requested by the pilot).

- 2) Assess the overall traffic situation and establish the maneuvering limits and desired separation function.
- 3) Coordinate potential clearance with adjacent sectors as appropriate.
- 4) Transmit the maneuvering limits and desired separation function to the airplane.
- 5) Monitor the situation to assure that no separation violations have, or are about to occur and resolve any conflicts so identified.

4.2.5.5 System Requirements and Concept

The system's basic functional requirements are to display the relative position of pertinent traffic and to provide guidance information for maintaining separation.

The following are the performance requirements and display concept for mechanizing the CDTI system.

4.2.5.5.1 Performance Requirements

The estimated performance requirements are:

Number of Targets - Six maximum.

Position Accuracy - Altitude data digitized in 100 foot increments and 1,000 foot accuracy in horizontal position accuracy.

Update Rate - Four seconds.

Coverage Volume (Displayed) - Selectable up to 10,000 feet above or below, 100 n.mi. range ahead and 50 n.mi. laterally.

Target Data - Basic target data is horizontal position, identity and altitude. Additional data required, either supplied or derived on-board, are climb rate and velocity vector.

Guidance Data - Data which may be required to implement a satisfactory guidance capability may include: (1) ownship velocity vector, altitude and climb rate; (2) altitude, longitudinal and lateral closing rates between ownship and selected target; and (3) computed climb rate or velocity vector for maintaining separation.

Guidance Accuracy - System should allow pilot to maintain separation to within ten percent (one sigma) of the minimum separation standard (i.e., 100 feet to 1,000 foot vertical separation and 1800 feet for 3 n.mi. horizontal separation).

4.2.5.5.2 Display

The display presents the target data and guidance information.

Basically the display shows the pertinent traffic overlaid on a plan position display of severe weather along the airplane's flight path (Figure 4.2.5-2).

The target aircraft can have data blocks showing identity, groundspeed, altitude, and climb rate and direction (up or down). The target symbol points along the velocity vector.

Ownship data block has groundspeed, altitude, and climb rate and direction.

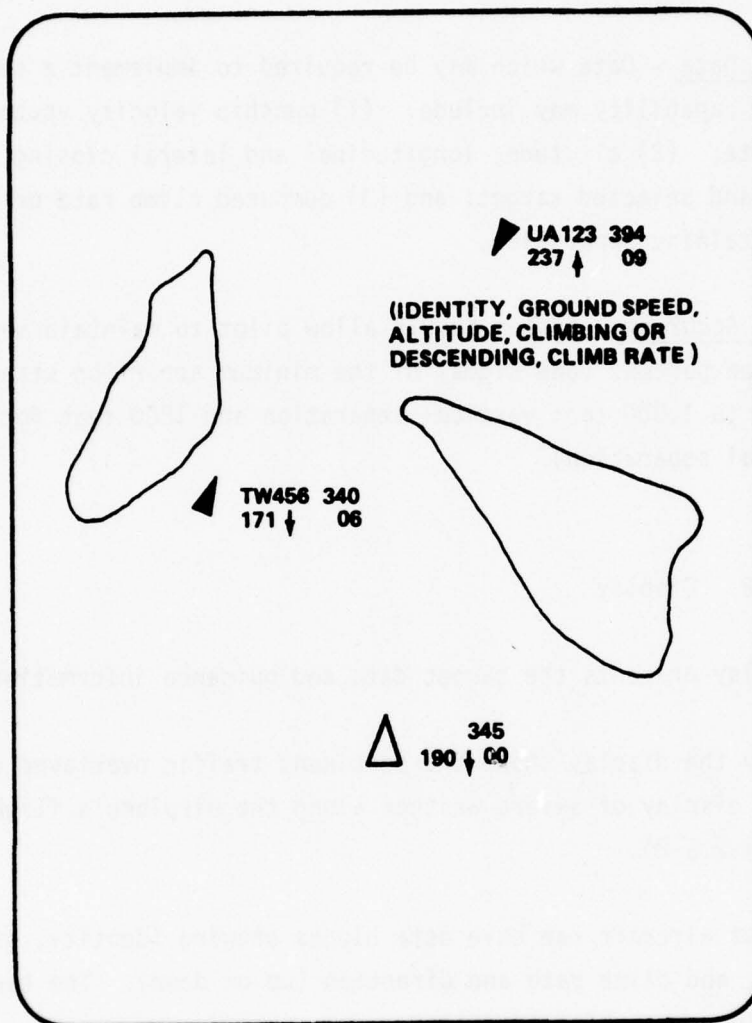


FIGURE 4.2.5-2 SEVERE-WEATHER AVOIDANCE DISPLAY

Additional guidance aids such as leaders or circles around targets representing required separation are possible and could be pilot selectable. However, considerable development is necessary before more than the basic display shown in Figure 4.2.6-2 can be defined.

The question arises of how both weather and traffic get on the same display. If separate displays were used, it would be difficult for the pilot to correlate target and weather cell positions. Thus, addition of the weather cell contours to the EHSI appears to be required for this CDTI role.

4.2.5.6 Potential Benefits

The advantages of the CDTI role is that the pilot would be avoiding severe weather; while also flying to insure separation from surrounding traffic.

The potential benefits are:

- 1) Increased safety by minimizing conflicts and maximizing severe weather avoidance.
- 2) Increased flow rate through areas of severe weather.

Additional benefits which might accrue under the right circumstances are:

- 1) A reduction in controller workload.
- 2) A reduction in air-to-ground communications.

4.2.5.7 Potential Problem Areas

The following are problem areas which identify analysis and testing needed to provide data for further development and evaluation of this CDTI role.

Pilot

- 1) The principal problem is the locating consistently of a path through weather while maintaining separation from other traffic.
- 2) Interference by the traffic separation task with the basic job of flying the airplane.

Operational

- 1) The controller would not know the intended path of the CDTI airplane, so might have difficulty in spotting conflict before drastic resolution alternatives become necessary.
- 2) When CDTI severe-weather avoidance involves more than one sector, the controller issuing the clearance may not have information on potentially conflicting traffic in the next sector.
- 3) When two or more flights have CDTI severe-weather avoidance clearances involving maintaining separation relative to each other, this situation must be communicated to all parties and planned actions coordinated.
- 4) If the CDTI pilot produces a conflict, ATC ability to successfully identify the conflict, intercede, and resolve the conflict may be a problem.

Design

- 1) The estimated performance requirements (number of targets, update rate, etc.) need to be verified by analysis and simulation.

- 2) The mixture of traffic and weather on the same display may be necessary. If so, selection of either the EHSI or weather radar display must be determined.

Performance

Flow rate through severe weather may be decreased with CDTI.

4.2.5.8 Test Scenario Considerations

A test scenario to evaluate the feasibility and performance of the severe-weather avoidance role appears impractical due to the randomness of severe-weather arrangements. The concept should be proven by using the CDTI under controlled conditions in actual operations.

Simulation and flight tests should concentrate on developing the CDTI design. For this purpose, several representative severe weather cell arrangements should be developed based on observation of actual weather. Airline pilots could be used to determine which arrangements represented the spectrum of probable encounters.

The weather arrangements could be read into selected traffic situations to test pilotage problems and CDTI design performance.

5.0 SYSTEM MECHANIZATION

The mechanization alternatives were investigated and an integrated CDTI system encompassing the various roles discussed in Section 4 was postulated. The postulated mechanization attempts to be capable of either the TMA monitor or ATC roles with appropriate recognition of items which need to be added or deleted based on whether monitoring or active control is being performed. This proposed system is representative of a possible mechanization in the Upgraded Third Generation environment.

5.1 Alternatives

The data source alternatives, computational workload division alternatives, and data-link considerations as they affect the recommended system mechanization were investigated.

5.1.1 Basic Traffic Data Source Considerations

The operating concept and data requirements for CDTI are particularly dependent upon the source of the display traffic information. The viable choices are:

- 1) Aircraft derived, and
- 2) Ground derived and telemetered to user.

The air derived option could offer the very significant advantage of being independently redundant to portions of the ground system and does not require an air/ground data-link capability. This type of redundancy would be most beneficial in the system backup mode. However, an air-derived system is not equal to a ground-derived system in several important ways which are: (1) identity information is not available (except transponder code); (2) ATC intent information is not available; (3) mapping or track information must be self-contained and would be less flexible; (4) the pilots are using a

different information source than the controller; and (5) the airborne CDTI equipment complement is likely to exceed that required for a data-link approach. However, normal air-derived operations are dependent upon the ATCRBS or DABS capability being operational.

If an air-derived system were to be mechanized with ATCRBS along the lines of Litchford's semi-active BCAS system (Reference 17) or the single site passive BCAS approach (Reference 18) operating in the normal ground cooperating mode, the following must be added:

- | | |
|------------------|---|
| Ground System: | 1 new pulse added to ATCRBS transmission or DABS transponders colocated with the SSR sites. |
| Airborne System: | 1 new 1090 MHz beacon receiver, data processing capability, modification to present beacon transponders to increase sensitivity and provide synchronization with the side lobe suppression subsystem (SLS), and diversity (top/bottom) antenna equipment. |

In the BCAS system, the measured or derived information is processed to determine collision avoidance commands or restrictions which are displayed to the pilot with warning annunciation. In the CDTI case, the information would be used to position surrounding traffic on the EHSI CRT. Data which can be derived from this system include range, range-rate, bearing angle, altitude, and transponder code identification.

Where ground surveillance interrogation and reply information is inadequate, a new 1030 MHz transmitter is required for the CDTI aircraft to interrogate actively other aircraft.

If no ATCRBS site is available, the aircraft will interrogate the surrounding traffic's beacon transponder. With this technique, azimuth information cannot be derived and the resultant information is range, range-rate, and altitude.

Hence, this mode which is truly independent of the ground system, is not a suitable CDTI information source due to the lack of azimuth information. The FAA/MITRE active BCAS system is not applicable because azimuth information is not available and hence this system does not provide the basic information required for CDTI implementation. This system would require a directional antenna system, which has not yet demonstrated the required bearing accuracy.

The second viable source of information for CDTI display is by data-link of data available in the ground system. The pertinent information which is, or could be, available includes relative position, altitude, aircraft identity, beacon code, maps and tracks, ATC intent, conflict alerting and resolution commands, automatic traffic advisory and resolution instructions, minimum safe altitudes and warning, groundspeeds, climb or descent indicators, aircraft type, VFR or IFR indicator, and flight plan intent.

The above information results from the ground system obtaining position and altitude from either ATCRBS or DABS with the balance coming from computation and/or storage of the NAS-Stage A or ARTS computer facility. This information would need to be transformed into CDTI airplane coordinates; possibly on the ground, but more likely in the airplane for at least the final coordinate rotation to achieve bearing with respect to aircraft track or heading.

Data-link capability is required for this option. If DABS were available, the logical choice for data transmission would be the data-link capability of that system if possible. Alternatively, a universal data-link approach could accomplish the transmissions. The universal data-link would require new ground and airborne equipment. Another possibility, in the absence of DABS surveillance, is the use of appropriate DABS ground transponders to uplink information via the data link all-call.

5.1.2 Ground Versus Airborne Computational Considerations

As all of the CDTI roles require a display of proximate traffic, the basic calculations involve the determination of horizontal separation distance and altitude difference from which a traffic proximity selection for each CDTI airplane can be made. The altitude computations can be made directly from the MODE "C" reports. The horizontal separation distance can be computed from the ATCRBS or DABS range and azimuth information corrected for altitude. As this calculation is similar or identical to that necessary for a basic

calculation is similar or identical to that necessary for a basic IPC parameter, only the selection process for the CDTI role(s) would be new. Any information block which is attached to the target traffic would necessarily have to be selected and formatted for each airplane.

Two distinct system mechanization alternatives present themselves for the above calculations. The first, as discussed above, is to accomplish calculations and the resulting formatting and data selection in the ground system computer and transmit only the pertinent traffic to each CDTI via the DABS data-link. The second is to broadcast the targets and data blocks for all area traffic to all airplanes, where the calculations and data selection would be accomplished by the airborne equipment. These two alternatives have different data-link implications which are discussed in the following section. They also differ computationally as discussed below.

With either alternative, it is assumed that coordinate rotation to aircraft heading and all display formatting is accomplished in the airborne CDTI computer. As the CDTI pilot may choose to operate his display in any of its possible roles, the traffic for a specific role will be selected by the airborne system from the total available proximate traffic (i.e., traffic associated with the most general monitoring role). Selection of the total proximate traffic itself is dependent upon which of the two alternative mechanizations is selected.

For purposes of discussion, it is convenient to refer to these alternatives as the "Broadcast Target Data" and "Ground Selected Target Data" options.

If the total number of airplanes in an area of concern (e.g., a terminal area) is N airplanes, the two options can be compared as shown in Table 5.1.2-1. In this table "computations" refer to the comparing of one airplane against another to determine whether the proximity conditions are satisfied. Data blocks refer to all data about any one target aircraft such as position, identity, groundspeed, sequence number, etc.

Computationally, the principal difference between the two options is that the

TABLE 5.1. - 1 COMPUTATION AND DATA-LINK TRADE MATRIX *

	ATC COMPUTER	DATA-LINK LOAD	CDTI COMPUTER	AIRBORNE COMPUTING -TOTAL-	REMARKS
<u>BROADCAST TARGET DATA</u> - COMPUTATIONS - DATA BLOCK HANDLING - FORMATTING - TRANSMISSION - DISPLAY - DISPLAY COORDINATE TRANSFORMATIONS	NONE	-	$\approx N$	$\approx N^2$	o MAJOR AIRBORNE COMPUTING LOAD o USER INVESTMENT COSTS HIGHER o BETTER DATA-LINK UTILIZATION o BUT REQUIRES UNIVERSAL BROADCAST CAPABILITY o FLEXIBLE DATA SELECTION
	N	-	-	-	
	-	$\approx N$	-	-	
	-	-	10	10N	
	-	-	10	10N	
<u>GROUND SELECTED TARGET DATA</u> - COMPUTATIONS - DATA BLOCK HANDLING - FORMATTING - TRANSMISSION - DISPLAY - DISPLAY COORDINATE TRANSFORMATIONS	$\approx N^2/2$	-	-	NONE	o MAJOR GROUND COMPUTING LOAD o FEWER TOTAL AIRPLANE-TO-AIRPLANE COMPUTATIONS o MAY BE POSSIBLE TO USE DABS BUT REQUIRES MORE TOTAL DATA-LINK TRANSMISSIONS o STANDARDIZATION EASIER o LOWER USER COST AND HENCE MORE CDTI EQUIPPED AIRPLANES
	10N	-	-	-	
	-	4N	-	-	
	-	-	10	10N	
	-	-	10	10N	

* BASED ON AVERAGE OF TEN PROXIMATE
TARGETS/AIRPLANE

Broadcast Target Data mechanization would have N airborne computers in parallel investigating N targets, whereas the Ground Selected Target Data option would be serially investigating N targets for a total of $N^2/2$ computations. In order for the update cycles to be equal, disregarding data-link differences, the ground computer would need to be approximately N/2 times as fast as the airborne computer. Algorithm efficiencies and credit for calculations already accomplished for other (e.g., IPC) purposes, may reduce this apparent difference.

5.1.3 Data-Link Considerations

Four apparent options for data-linking CDTI information are:

- 1) Transmit all area traffic discretely to each airplane,
- 2) Transmit selected proximity traffic to each airplane,
- 3) Transmit all area traffic via broadcast to all airplanes simultaneously, and
- 4) A hybrid combination of selected and broadcast data.

The first of these options would require a data-link capability which could transmit N data blocks to N airplanes on each update cycle. As the number of airplanes, N, in the area could be several hundred, this technique would pose an unnecessarily large data-link load and is rejected for further consideration for the multitude of technical problems associated with this loading.

The second option would require the transmission of only selected proximate traffic individually to N airplanes. If it is assumed an average of ten airplanes in proximity to each CDTI airplane, the data-link load per update cycle would be on the order of ten N target data blocks. This amount of data may represent a tractable load for the DABS data-link capability, but is still a great deal of data to be handled on a short (approximately 4 seconds) update cycle. As the target data blocks must be received every update cycle, this represents a continuous, non-deferrable data-link load. The nature of

the CDTI system does not appear to allow only partial target data transmission per DABS scan, but rather all target data needs to be transmitted on each scan. One other aspect of this option is that it is unlikely that all N aircraft will be CDTI-equipped so in practice only a fraction of the ten N target data blocks would need to be transmitted.

The third option requires the broadcasting of N target data blocks to all airplanes simultaneously. This technique is not at present DABS compatible, but offers a number of total system advantages. Both ground computations and data-link load are minimized by this approach, at the expense of an increase in air borne computing capability. While this option is conceptually attractive, the technical details of the data-link need to be formulated. This approach might be a viable option should a universal data-link capability become part of the advanced ATC system capability.

An attempt to size the data-link requirements is discussed below. If a DABS type mechanization were considered using the comm-C format (Reference 19), up to 16 message segments containing 80 data-bits per segment in the ground-to-air message field could be transmitted per single airplane acknowledgment.

From consideration of the data to be transmitted and the number of bits to encompass the data parameter range, a hypothetical allocation of the necessary data fields are shown in Figures 5.1.3-1 through 5.1.3-3.

Figure 5.1.3-1 illustrates a single 80-bit segment containing CDTI ownship data from which all relative track geometry and target traffic in following message segments is positioned for display. This message format illustrates certain other command or information data which is necessary for one or more CDTI roles. For example, if it is necessary to provide track information to illustrate a merge situation, bit 79 of the ownship message would indicate that track geometry follows in the next message segment.

Figure 5.1.3-2 illustrates the use of an 80-bit segment for transmitting track geometry information including beam control bits indicating how the

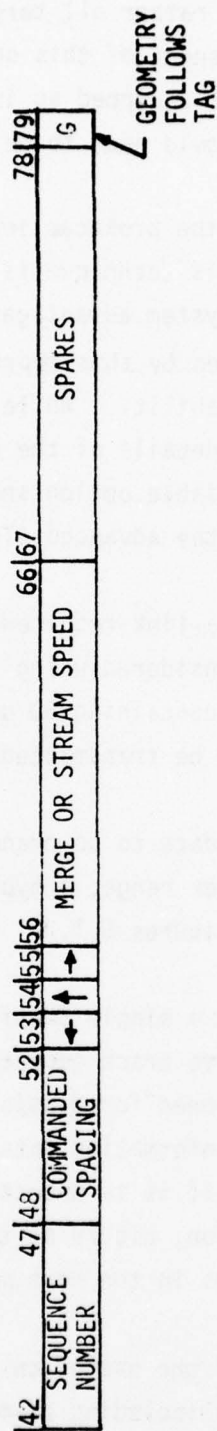
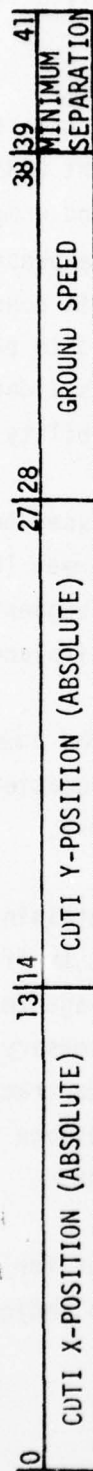
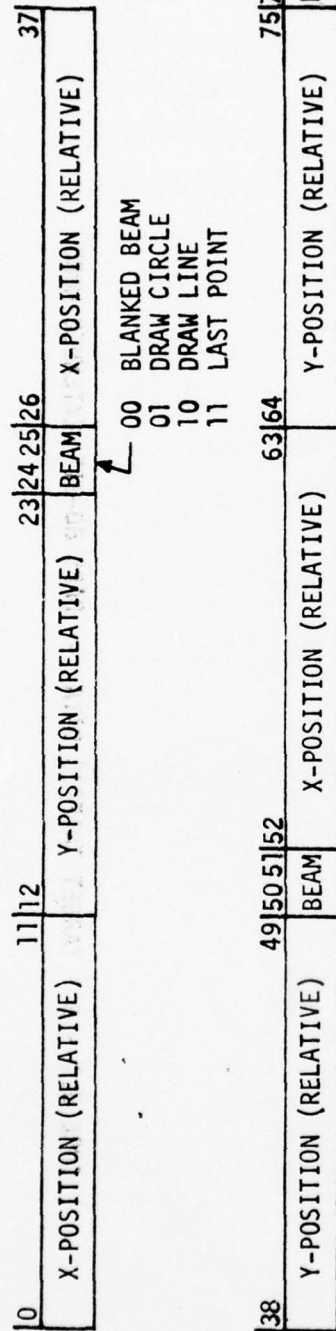


FIGURE 5.1 - 1 CUT I OWNERSHIP DATA - JABS 80-BIT EXTENDED WORD



GEOMETRY
FLAG
FOLLOWS
SPARE

FIGURE 5.1 - 2 TRACK GEOMETRY DATA - DABS 80-BIT EXTENDED WORD

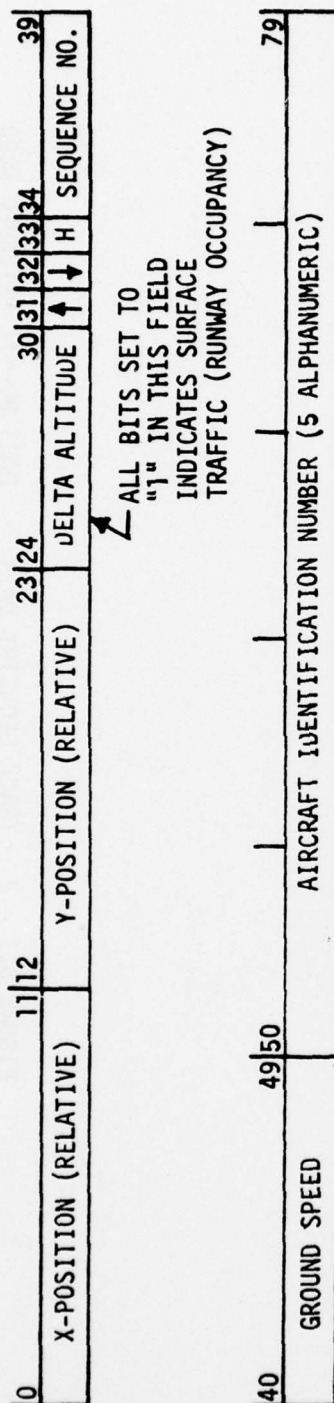


FIGURE 5.1 - 3 TARGET TRAFFIC DATA - DABS 80-BIT EXTENDED WORD

CDTI display is to use this information. This allows for repositioning the CRT beam and for drawing straight lines and circular arc segments between successive x-y pairs for a given track geometry. It is believed that only one or two 80-bit segments would be normally used for the CDTI roles, but if more are necessary they can be chained by setting bit 79, indicating that more track geometry is following.

The total number of 80-bit message segments which must be transmitted to each CDTI airplane on each update cycle can now be bounded as follows:

$$\text{Message Segments} = \text{Ownship Segment} + \text{Track Geometry Segments} + \text{Target Segments}$$

If the assumption of ten proximity targets per CDTI airplane and two track geometry segments were made, the total 80-bit message segments per CDTI update would be 13 (of the available 16) or a total of 1040 message bits. Our understanding of the DABS characteristics is that each message segment requires 50 microseconds for an average CDTI update.

Several key assumptions need further investigation. These involve questions of whether DABS can transmit an entire 16 segment comm-C message on a single scan and can this be done on a continuous basis for the number of CDTI-equipped airplanes. These questions must be posed to investigators knowledgeable in the detail workings of DABS before this mechanization could be judged suitable for general purpose operation. One further question is whether comm-C messages can be chained on a single scan should the number of targets require exceeding the 16 segments available in a single comm-C message.

Factors effecting both data-link and computational loading are the total number of targets, N, in an area of concern and the fraction of these which are CDTI equipped. N represents the peak instantaneous airborne count plus those using the active runways of the airport(s). Reference 20 indicates a possible upper bound on N. For a 60 nautical mile cylinder centered on

Los Angeles International airport. This report indicates a total of 743 targets (for 1982) of which 716 are below 10,000 feet. General CDTI usage in this situation would significantly burden a DABS system; suggesting that careful design of algorithms and hardware load division (e.g., multiple DABS data-links sharing the Los Angeles basin load) may be necessary.

If a more general purpose data-link which could broadcast to all airplanes were to be used for the CDTI data, the data transmission requirements might be bounded by the following approach. Using the same message format, each of the CDTI aircraft would require one ownship segment and two track geometry segments. In addition, a segment for each of the N targets needs to be broadcast. These considerations imply a total of four N 80-bit message segments per update cycle. Using $N = 743$ for the 1982 Los Angeles basin yields

$$\text{Message Bits/Update} = 4 \times 743 \times 80 = 237,760$$

Allowing a buffer for synchronization, parity, etc., might increase this to 250,000 bits/update. A four-second update would require a data-link capability of approximately 62,000 bits/second. This broad band system may not be feasible with any probable allocation of VHF channels, and implies that a general broadband data-link capability for CDTI would need to be in the upper frequency spectrum (e.g., L-band). For comparison purposes, if all aircraft are CDTI-equipped, the DABS bit rate would be about 250,000 bits/second. The above calculations are based on 100% of the aircraft being CDTI-equipped. This may be an operationally unrealistic assumption, but for the purpose of bounding the worst-case data-link requirements is the conservative choice.

A hybrid system is possible in which all target data are broadcast on a general purpose data-link with ownship and track geometry data transmitted using DABS. Since ownship and track information except that obtainable from the ownship target broadcast tends to remain constant over a number of update cycles, considerable DABS efficiencies can be achieved. If ownship and track data were only necessary once every 15 update cycles and using

the previous assumptions, data load of the system would be

$$\text{Broadcast bits/second} = (N \times 80)/4 \text{ -- } 15,000 \text{ bits/second}$$

$$\text{DABS bits/second} = (N \times 80 \times 3)/(4 \times 15) \text{ -- } 3,000 \text{ bits/second.}$$

This represents an easier way to handle the data-link requirements of busy terminal areas with existing technology. However, even with the hybrid, the broadcast data-link requires more band-width than currently discussed for L-band systems.

The considerations in this section are for concept exploration and bounding the data-link requirements. These large data-link requirements suggest that a more limited implementation (e.g., CDTI service provided only in arrival/departure mixed airspace corridors) may be more cost effective.

5.2 Requirements

The following requirements are imposed by consideration of the individual roles and the computational, data-source, and data-link considerations of Section 5.1. These requirements are based on the assumption that the ultimate CDTI mechanization will be DABS data-link compatible; recognizing that considerable additional work is needed to define the system.

CDTI Airplane

The CDTI airplane must have:

- 1) An EHSI or similar display system capable of providing control and display of the CDTI capabilities integrated with the normal EHSI functions. Principally, this requires the ability to overlay target traffic, data blocks, track structures, command information, and runway configurations. Flexible display scale selection integrated to the EHSI scale selection is required.

- 2) A DABS transponder with data-link.
- 3) An IPC capability. This results from the choice to provide proximate traffic to the CDTI system as opposed to traffic selected using a tau criteria.
- 4) A CDTI computing capability. This computing capability must make coordinate transformations to aircraft heading or track, select the traffic of interest for a particular role, manage the CDTI controls and display, provide motion compensation for coasting and image motion compensation and manage the data-link interface and formatting down-link replies. This system should be capable of managing at least 20 active targets simultaneously.
- 5) DABS data-link-to-computer interface hardware.

ATC Ground System

The ATC ground system must have:

- 1) DABS with data-link. The data-link must be capable of servicing all airplanes within the CDTI service volume.
- 2) An improved airport surface surveillance system such as the Tower Automated Ground Surveillance (TAGS) system.
- 3) Data interfacing capability between the improved airport surface surveillance system, ARTS-III, NAS-Stage A, and the DABS data-link.
- 4) IPC service.
- 5) Computing capability to determine which targets are within the proximity of other targets; to select the proximate targets and their data blocks; to select spacing, separations, and sequencing requirements for each

CDTI airplane, and to provide formatting and control for the DABS data-link. This computing capability must also support controller display management for possibly CDTI unique features associated with identification, clearances, and handoffs.

Pilots and Controllers

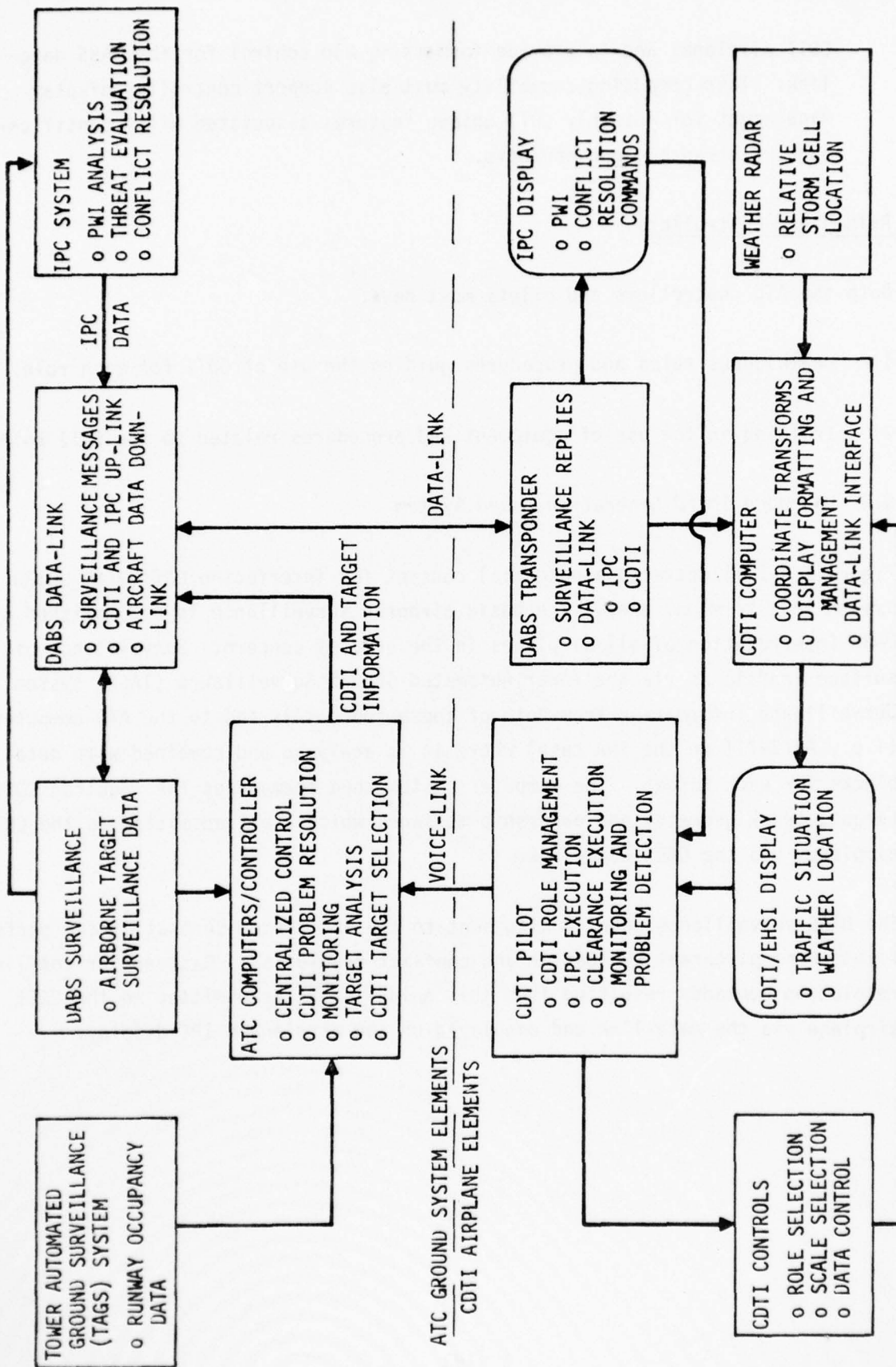
Both the ATC controllers and pilots must have:

- 1) Unambiguous rules and procedures guiding the use of CDTI for each role.
- 2) Training in the use of equipment and procedures related to the CDTI roles.

5.3 Upgraded Third Generation Based System

Figure 5.3-1 illustrates a potential concept for interfacing CDTI with UG3RD system in a terminal area. The basic airborne surveillance is accomplished by DABS interrogation of all airplanes in the area of concern. Surveillance of surface traffic is via the Tower Automated Ground Surveillance (TAGS) system. Surveillance information from both of these sources is fed to the ATC computers (i.e., ARTS-III in the TMA case) where it is analyzed and combined with data blocks for each target. The computer system then formulates the required CDTI target, track geometry and ownership messages which are transmitted to the CDTI airplanes via the DABS data-link.

The DABS surveillance data is also sent to the IPC system so that it can perform pilot warning; threat evaluation and conflict resolution. Data and/or conflict resolution commands resulting from this analysis are transmitted to the CDTI airplane via the data-link and displayed on the airplane's IPC display.



The controller formulates and negotiates and clearances associated with the CDTI roles and transmits them either by voice or the ownship data link, or by both to the CDTI pilot.

The CDTI pilot is responsible for the control and management of the CDTI roles using the CDTI display. He also is responsible for executing IPC commands presented on the IPC display. His CDTI display control for roles selection, scaling, and control of displayed data is the CDTI control panel which alerts the CDTI computer of his selections.

The CDTI computer analyzes the CDTI data coming in from the DABS data-link, based on the pilot's selection of role to be displayed and data desired.

Coordinate transformations are required so that the CDTI elements are displayed coherently with the basic EHSI data (e.g., heading or track-up display). This computer also formats for display the relative position of severe weather cells when that role is being used. While the CDTI computer is diagrammed as a separate box, these functions would most likely be included in the EHSI computer as CDTI is considered a subfunction of that system.

5.4 Airplane System

The purpose of this section is to explore airborne equipment implications of the combined CDTI roles investigated in this study.

Combinations of the various roles are probably desirable. For example, after accomplishing a CDTI arrival merging, the airplane would transition naturally to a longitudinal separation monitoring role. Similarly, while monitoring a close-spaced parallel approach, the CDTI pilot would simultaneously be monitoring the runway occupancy situation. Combined monitoring

and ATC roles also occur. For example, general TMA monitoring and arrival in-trail spacing (an ATC role) are simultaneously compatible. The ability to combine active ATC and passive monitoring roles will require careful design at all levels. Some roles are mutually exclusive either because they apply to different flight phases or because they are competitive in purpose and means of accomplishment. Based on the assumption that the airborne computer will perform necessary checks to assure role compatibility, the pilot's CDTI functional control requirements can be investigated.

The pilot's control requirements include the following functional capabilities:

- 1) CDTI mode selection. This control would initiate the EHSI/CDTI subfunction.
- 2) A control to allow selection of any role, or any set of compatible roles.
- 3) A control to allow selection or suppression of CDTI track geometry.
- 4) A control to select or suppress target traffic identification labels.
- 5) A control to select or suppress the entire target traffic data block.
- 6) A control to allow for changing the relative brightness on the display of CDTI versus EHSI normal mode data.
- 7) A control to select the display scale. As CDTI data is envisioned as being overlaid on EHSI data, this control is the same as that used for EHSI. However, the EHSI scales available must be investigated to assure that the scales desirable for CDTI purposes are available.

All other controls (e.g., display on/off, total display brightness level, etc.) are assumed to be part of the EHSI control system. The EHSI display must be capable of presenting the data as required for each CDTI role or role combination.

6.0 BENEFITS ANALYSIS

The CDTI roles have been analyzed to determine potential benefits. The results are described in the following section. First the assumptions used are outlined and then each of the roles evaluated are covered. Finally, a qualitative discussion of other benefits possible is presented.

6.1 Assumptions

The purpose of assessing the CDTI potential benefits is to show those roles that have promise of resolving busy terminal area problems in a cost/benefit manner. This will lead to flight test plans to verify the assumptions made in the benefits study and to further refine the system concept and requirements. Since the end result is to be a relative comparison of the CDTI roles, it is important to maintain consistent assumptions and methodology so that although absolute results may have large uncertainty, the relative results are valid. For example, benefits that attained from delay reduction are dependent on assumptions about the amount of delay that would be tolerated. Even small growth at saturated airports would theoretically lead to unacceptable delays. This would enable small capacity improvements to show large delay savings that would never realistically occur. However, the relative results are significant.

Benefits from reduced delay and increased operations are not always independent. In some cases a delay reduction potential assumes that operations rates do not increase. Alternatively, the benefit can be used to increase operations with the same delay. In other words, concepts increasing capacity at airports yield benefits that can be traded (delay against operations). The actual benefit depends upon whether or not additional demand exists to permit increased operations or significant delay exists to be reduced.

It is assumed that each concept will accomplish the intended function. For example, if the CDTI equipment allows closer safe spacing between airplanes, it will follow that operation rates will increase - although a possibility exists that the present spacing will be maintained for other reasons. Also, the assumption is made that the design characteristics of the equipment are sufficient in that they satisfy the requirements imposed by the concept (position accuracy, collision avoidance, response time, etc.).

The study is performed assuming all airplanes are equipped, capacity gains are calculated for air carrier airplanes and airports.

Finally, in order to obtain a benefit quantification for future systems, a demand level consistent with the other study parameters is specified. Demand levels through the year 2010 extrapolated from FAA forecasts are used.

6.2 Independent Parallel Approach Monitor

A reduction in the minimum lateral spacing between IFR independent runways has been under active discussion for more than ten years (Ref.3 and 20). The present standard was recently reduced to 4300 feet (1310 m). This is a regulatory action for which the technical factors were:

- ILS and aircraft final approach navigation accuracy
- Surveillance system accuracy and update rate
- Evasion command capability for protection against blunder
- Ground control decision algorithm (position-only, with no-transgression zone, position-velocity, and so forth).

Further improvements in this area may be expected to come in stages:

- Reduction to 3500 feet (1065m) with improved surveillance update rate and cross-course accuracy.
- Reduction to 3000 feet (812 m) with full improved surveillance and data link.

The operational goal has been set for 2500 feet (760 m) in the upgraded third generation system (Reference 3). The proposed CDTI role is to provide traffic information on approach to parallel runways so that under instrument meteorological conditions (IMC) pilot confidence can be at a level closer to that under visual conditions. This confidence would aid in acceptance of a reduction in the parallel independent approach runway spacing requirements. The reduction in parallel runway minimum separation standard for instrument approach operations can provide increased capacity and reduce delay at some air carrier airports. An examination of the 50 busiest U.S. aircarrier airports indicates 15 airports would obtain increased capacity under instrument conditions by reducing the present parallel runway minimum (4300 feet) to 2500 feet. Reduced delay will have a substantial impact on direct operating costs including fuel savings.

As the 50 busiest aircarrier airports are examined, two questions are considered:

- 1) Will the forecast traffic exceed existing IFR capacity within the next 30 years, and ,
- 2) Do the existing airport configurations have parallel runway pairs with separations between 2500 and 4300 feet?

Results for the top 50 air carrier airports indicate:

- 1) Six airports would obtain required increased capacity.
- 2) Nine airports would obtain increased capacity, but traffic forecast levels indicate a requirement for the capacity will not exist within the next 30 years.
- 3) Eighteen of the busy airports will need additional capacity, but their current configurations are such that the reduction of separation minimums will not help.

Table 6-1 provides a list of the 50 busiest air carrier airports based on 1974 operational data (Reference 22). For each tower, the 1974 instrument approach rank is given (Reference 22) together with the estimated year when airport IFR capacity will be (has been) exceeded. The runway system of each of these airports is also identified and divided into parallel runway systems (with associated separations) and other runways.

The airport capacity estimate is based on an analysis of operations at busy air carrier terminals for the Strategic Control Algorithm Development program (Reference 14). This analysis compares traffic growth postulated for major airports with IFR capacity data based on FAA Advisory Circular 150/5060-3A (Reference 23). Airport configuration data is based upon Jeppesen Approach plates (Reference 24). The estimates of Reference 4 have been updated using latest terminal area traffic forecasts supplied by the FAA (Reference 25).

Based on the data contained in Table 6-1, three airport groups have been determined (Table 6-2). Airports in Group "A" have now (or will have within 30 years) significant IFR capacity problems. These airports also have existing parallel runway systems with separations of between 2500 (the FAA operational goal for a fully automated ATC system) and 4300 feet (the current minimum). Group "B" airports are projected to have no significant capacity problems, but have parallel runways between the 2500 and

TABLE 6-1 FIFTY BUSIEST AIR CARRIER AIRPORTS

1974 AIR CARRIER OPERATIONS RANK	AIRPORT	1974 INSTRUMENT APPROACH RANK	ESTIMATED YEAR WHEN IFR CAP. EXCEEDED	PARALLEL RUNWAY SYSTEM	RUNWAY SEPARATION (FEET)	OTHER RUNWAYS
1	Chicago O'Hare	2	Present	4/22, 14/32, 9/27	1000, 6000, 5400	18/36
2	Atlanta	3	1979	9/27, 8/26	1050, 4400	15/33
3	Los Angeles	1	1977	6/24, 7/25	700, 4500, 750	
4	John F. Kennedy	8	Present	13/31, 4/22	5000, 3000	14/32
5	Dallas-Fort Worth	21	Present	17/35	6450	13/31
6	San Francisco	9	Present	1/19, 10/28	700, 770	
7	LaGuardia	5	Present	13/31, 14/32	1600	4/22
8	Miami	15	1981	9/27	5100	12/30
9	Washington National	16	Present	None	N.A.	3/21, 15/33, 18/36
10	Denver	50	Present	8/26	840	17/35
11	Boston	11	1984	4/22, 15/33	1400, 1500	9/27
12	Pittsburgh Greater	4	1978	10/28	4200	14/32, 5/23
13	St. Louis	17	Present	12/30	1300	6/24, 17/35
14	Detroit Wayne	14	---	3/21	3700	15/33, 9/27
15	Philadelphia	24	---	9/27	1440	17/35
16	Newark	32	1977	4/22	1000	11/29
17	Minneapolis Mold Chamber	18	1979	11/29	3500	4/22
18	Cleveland Hopkins	6	1983	18/36, 10/28, 5/23	800, 3700, 500	
19	Houston	19	1997	None	N.A.	8/26, 9/27, 14/32, 13/31
20	Honolulu	43	---	4/22	625	8/26
21	Memphis	20	---	17/35	3430	3/21, 9/27, 14/32
22	Seattle-Tacoma	7	---	16/34	750	17/35
23	Kansas City	44	---	None	N.A.	1/19, 9/27
24	Las Vegas	261	1977	1/19	820	7/25
25	Tampa	79	---	18/36	4330	9/27
26	New Orleans Moisant	45	1982	None	N.A.	4/22, 8/26, 13/31, 17/35
27	Phoenix	646	---	8/26	3750	
28	Indianapolis	22	1984	4/22	2750	13/31
29	Covington Gr. Cinn.	28	Present	9/27	1800	18/36
30	Milwaukee Mitchell	29	---	1/19, 7/25	800, 3600	13/31

TABLE 6-1 FIFTY BUSIEST AIR CARRIER AIRPORTS (Continued)

1974 AIR CARRIER OPERATIONS RANK	AIRPORT	1974 INSTRUMENT APPROACH RANK	ESTIMATED YEAR WHEN IFR CAP. EXCEEDED	PARALLEL RUNWAY SYSTEM	RUNWAY SEPARATION (FEET)	OTHER RUNWAYS
31	Portland	26	---	10/28	3200	2/20
32	Buffalo	36	---	None	N.A.	5/23, 14/32
33	Baltimore	40	1990	15/33	3600	10/28, 4/22
34	San Diego Lindbergh	10	1981	None	N.A.	9/27, 13/31
35	Fort Lauderdale	268	---	9/27	3900	13/31
36	Charlotte	25	---	None	N.A.	5/23, 18/36
37	Windsor Locks	37	---	None	N.A.	1/19, 6/24, 15/33
38	San Juan	319	---	None	N.A.	7/25, 10/28
39	Salt Lake City	195	---	16/34	3000, 3900	14/32
40	Columbus	23	---	10/28	2800	1/19, 5/23, 13/31
41	Oakland	42	1992	9/27, 11/29	960, 5400, 7775	15/33
42	Orlando Jetport	252	---	18/36	1200	12/30
43	Washington Dulles	57	---	1/19	6700	18/36
44	Dayton	41	---	6/24	5000	1/19, 6/24, 11/29
45	Louisville Standiford	39	---	None	N.A.	17/35
46	San Antonio	33	---	3/21, 12/30	3900, 960	13/31
47	Nashville	31	---	2/20	1600	11/29
48	San Jose Municipal	35	---	12/30	700	12/30
49	Okl. City Will Rogers	59	---	17/35	5000	1/19, 4/22, 7/25, 10/28
50	Rochester	13	---	None	N.A.	

TABLE 6-2 INSTRUMENT APPROACHES AT APPLICABLE AIRPORTS

AIRPORT		INSTRUMENT APPROACHES (1974)		
GROUP	NAME	AIR CARRIER	AIR TAXI	GENERAL AVIATION
A	New York - JFK	17,729	1,490	1,010
A	Pittsburg	21,702	5,013	4,881
A	Minneapolis	10,972	1,380	3,428
A	Cleveland	16,799	2,377	3,618
A	Baltimore	4,959	2,100	2,665
A	Indianapolis	8,609	1,389	5,311
A	TOTAL	80,770	13,749	20,913
B	Detroit	13,651	1,410	3,667
B	Memphis	8,698	2,154	5,035
B	Phoenix	166	16	59
B	Portland	7,671	560	4,071
B	Milwaukee	7,530	709	3,382
B	Fort Lauderdale	711	142	542
B	Salt Lake City	1,417	187	440
B	Columbus	6,752	1,272	5,929
B	San Antonio	5,650	747	4,595
B	TOTAL	52,246	7,197	27,720
C	Chicago - ORD	43,242	4,134	2,423
C	Atlanta	38,843	1,290	4,361
C	Los Angeles	50,680	7,124	5,765
C	San Francisco	16,952	302	2,224
C	New York -LGA	22,378	1,508	4,487
C	Miami	12,821	2,034	3,879
C	Washington-DCA	12,323	1,997	3,355
C	Boston	14,019	3,446	1,961
C	Denver	5,741	542	1,594
C	St. Louis	11,836	1,595	3,934
C	Newark	7,900	1,765	2,179
C	Dallas-Fort Worth	13,663	1,716	639
C	Houston	1,303	1,075	6,721
C	New Orleans	6,306	548	1,631
C	Las Vegas	1,088	49	278
C	Cincinnati	9,535	1,267	1,861
C	San Diego	10,622	1,373	7,392
C	Oakland	4,364	502	4,011
C	TOTAL	283,616	32,267	58,695
A B C	TOTAL	416,632	53,213	107,328
U.S. TOTAL	INSTRUMENT	780,881	178,495	747,136
	ALL APPROACHES	4,601,363	1,291,109	21,561,703

4300 feet separation. Finally, Group "C" airports have or will have capacity problems, but do not have parallel runway systems between 2500 and 4300 feet. Of the 50 airports considered, six belong to Group "A" and would appear most likely to benefit from the postulated separation reduction, 9 belong to Group "B", and 18 to Group "C". Three of the six Group "A" airports require further discussion.

Airspace and noise problems at Kennedy will limit the benefit of independent parallel operations. Still the FAA report on airport capacity (Reference 21) identifies a considerable improvement in runway acceptance rates by making the 4/22 pair independent under IFR rules. Also, the Cleveland and Baltimore airports could not sustain air carrier operations on the existing parallel runway systems. Some runway improvements would be required such as lengthening runways.

Other possible benefits associated with the reduction of parallel approach minimums under IFR operations may apply to general aviation and air taxi users and airfields. General aviation and air taxi IFR operations have experienced rapid growth from 1972 to 1975. Table 6-2 shows a significant number of air taxi and general aviation instrument approaches at the analyzed air carrier airports.

In addition, some predominantly general aviation airports could have benefit. Table 6-3 lists some of the statistics. At the present time, however, none of these airports would be able to take immediate advantage of a 2500 feet rule so that the benefit application is less direct than in the Group "A" and "B" air carrier airports.

The translation of the preceding into benefit derives from the increase in operations and the reduction of delay under instrument conditions at the Group "A" and "B" airports. The potential increase in annual operations capability at the two airport groups is shown in table 6-4. This table assumes the following:

TABLE 6-3 GENERAL AVIATION INSTRUMENT APPROACHES

AIRPORT	I N S T R U M E N T A P P R O A C H E S		
	AIR CARRIER	AIR TAXI	GENERAL AVIATION
Santa Ana	4,440	1,352	13,402
Long Beach	675	317	11,355
Seattle Boeing	97	716	6,423
Van Nuys	0	1	5,870
Islip	5,364	49	5,582
Fullerton	0	1,346	4,102
Teterboro	210	857	3,266
TOTAL	10,786	4,638	50,000

- Runways were considered available independent of wind conditions
- Mixed operations on both runways
- Independent runway operation - i.e., operations rates equal twice single runway rates.
- Seventeen hour airport day
- Probability of instrument conditions is equal to the air carrier instrument approach to total air carrier approach ratio.

Single runway IFR operations rate estimates vary as a function of aircraft mix, runway configurations, arrival/departure ratios, delay tolerated, etc. The ATCAC report (Reference 3) estimates 38 mixed operations for today's typical runway and air carrier mix. The Boeing LAND model estimates 39 for the same assumptions. Because of the advantages of using an available and controlled model and the need for consistency in the study, the Boeing model results are used.

The assumption of independence yielding twice the single runway rates gives a parallel IFR result of 78. This figure is probably conservative since some advantages can be gained by proper sequencing of arrivals and departures between the runways that is not available to the single runway.

The IFR capacity of a dependent parallel runway pair (2500 feet separation) using the assumptions mentioned under the single runway case is 50 operations per hour.

The gain under instrument conditions therefore is 28 operations ($78-50=28$) per instrument hour. Table 6-4 indicates that the gains possible from this improvement represent about 4.59 percent of the total U.S. 1974 air carrier operations. Large percentage gains are shown for some of the individual airports. This is mostly a function of the actual number of operations in 1974 for the feasible airports. Under higher demand conditions (where the need is greatest), the percentage increase is a direct function of the amount of instrument weather. In most cases this would be under 10% of the total operations.

TABLE 6-4 AIRPORT OPERATIONS INCREASE

AIRPORT		INSTRUMENT CONDITIONS		OPERATIONS	ANNUAL INCREASE	
GROUP	ID.*	PROBABILITY	HOURS		% OF OPERATIONS TOTAL	AIR CARRIER
A	JFK	.124	2.1	21,462	6.3	7.5
A	PIT	.241	4.1	41,902	14.5	23.3
A	MSP	.169	2.9	29,638	12.4	22.8
A	CLE	.287	4.9	50,078	20.1	40.1
A	BAL	.140	2.4	24,528	11.1	34.6
A	IND	.202	3.4	34,748	18.2	40.1
B	DTW	.169	2.9	29,638	12.0	18.4
B	MEM	.160	2.7	27,594	9.2	25.4
B	PHX	.004	0.1	1,022	0.2	1.2
B	PDX	.204	3.5	35,770	19.6	47.5
B	MLW	.199	3.4	34,748	15.0	46.0
B	FLL	.022	0.4	4,088	1.3	6.4
B	SLC	.049	0.8	8,176	3.6	14.1
B	CMH	.238	4.0	40,880	15.6	72.0
B	SAT	.218	3.7	37,814	18.4	73.0
A & B TOTAL		--	--	422,086	10.8	26.2
U.S. TOTAL		--	--	422,086	0.73	4.59

* See Table 6-2 for name

The annual operations gains discussed in the previous section are an upper limit that would be obtained only when both groups of airports reach demand levels high enough to approach capacity (as defined in Reference 23). For present day airport configurations and rules, the year at which this occurs is given in Table 6-1. This shows that six airports would gain increased operations from CDTI-parallel operations in the next 30 years.

These six airports have been analyzed in further detail to determine capacity benefits during the 20 year time period of 1980 to 1999. Figure 6-1 shows the results as a function of year. To determine the number of operations, the following assumptions are made:

- Demand constraints are imposed when the demand is equal to the practical annual capacity.
- Demand forecasts are obtained from Reference 7 for 1976 to 1986 and extrapolated from there on.
- CDTI-parallel operations are initiated at all six airports by 1980.

With these assumptions, the following air carrier operations gains are estimated:

- Total Increase = 1,735,000 operations (20 years)
- Annual Gain After Year 2000 = 206,000 operations/year.

For estimation of delay, the method described in "Airport Capacity Criteria Used in Preparing the National Airport Plan" (Reference 26) is used. The method estimates an annual delay for airports operating at annual demand levels close to their practical annual capacity. It can be applied to levels both above and below practical capacity. For an airport operating at its practical annual capacity, the average delay per operation is estimated at 1.5 minutes per operation. Of course, throughout the year, varying conditions, peaking characteristics, accidents, severe weather airport closures, etc. cause large swings above this average value. For this analysis, however, the total average delay figure given seems most appropriate. To estimate the delay at the six airports, the same assumptions and demands levels assumed previously are used. It is assumed that in the

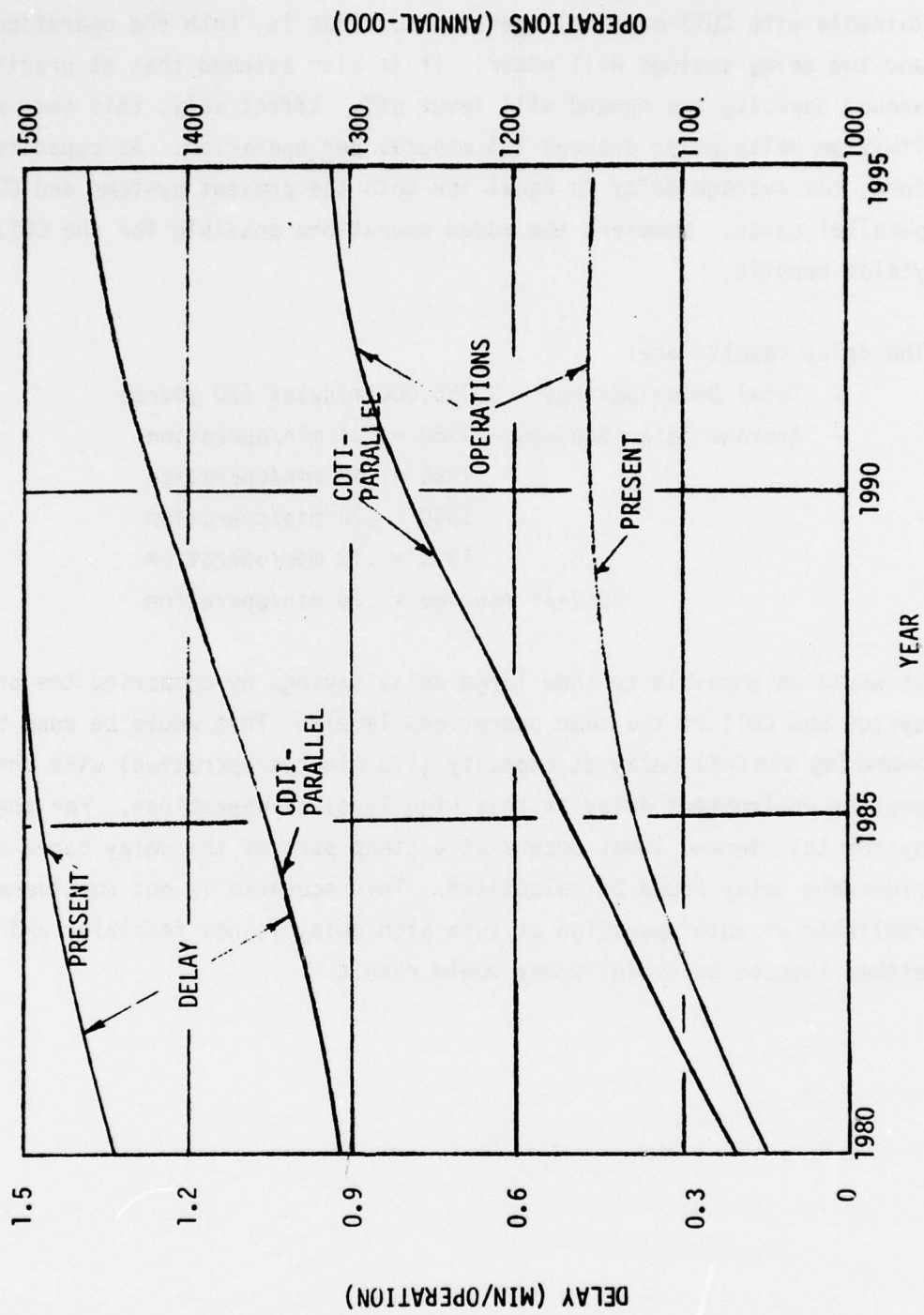


FIGURE 6-1 - CAPACITY BENEFITS FROM CDTI-PARALLEL RUNWAY OPERATIONS

CDTI parallel case the airports operate with the higher demand level obtainable with CDTI-parallel operations. That is, both the operations gains and the delay savings will occur. It is also assumed that at practical annual capacity the demand will level off. Effectively, this sets an upper limit on delay at an average 1.5 minutes per operation. At capacity, therefore, the average delay is equal for both the present systems and CDTI-parallel cases. However, the added operations possible for the CDTI still yields benefit.

The delay results are:

- Total Delay Savings = 3,765,000 minutes (20 years)
- Average Delay Savings - 1980 = .31 min/operation
1985 = .40 min/operation
1990 = .24 min/operation
1995 = .12 min/operation
20 Year Average = .16 min/operation

It would be possible to show large delay savings by comparing the present system and CDTI at the same operations levels. This would be done by comparing the CDTI delay at capacity (1.5 minutes/operation) with the present environment delay at this high level of operations. For the present system this demand level occurs at a steep part of the delay curve and considerable delay would be calculated. This scenario is not considered realistic because operation at such high delay is not feasible; and constraints, either imposed or evolutionary would result.

A detailed conversion of these results into dollar values to the airports, the public and the airlines has not been made in this study. In the case of improved IFR operational capability, average delay results can be misleading as to actual value. The following factors become more important:

- Airport at which disruption occurs - Some can cause system-wide problems that multiply the effect.
- Time duration of IFR weather incidents
- Number of diversions
- Secondary expenses (alternate routings, passenger accommodations, added pay cost, etc.)
- Value assigned to passenger inconvenience
- Expense of standby equipment.

All of these factors must be considered in evaluating the benefit of improved IFR weather operation.

6.3 Arrival In-Trail Spacing Control

One use of CDTI is as a spacing aid in the terminal area. An ATC instruction would be issued to an aircraft to target on and follow (at the required safe separation) a preceding aircraft that is being vectored from an arrival fix to the ILS. In the area of capacity benefit, the gain is a function of the ability of this method to improve the delivery accuracy over the accuracy of the assumed baseline methods.

One of the factors involved in the required spacing between airplanes on final approach is the outer marker delivery accuracy. This is because additional spacing (buffer time) must be introduced to prevent delivery errors from causing violations of the minimum separation standard. For example, although the minimum spacing allowed today is 3 n. mi., the average spacing must be increased to about 4 n. mi. to insure a high confidence of not violating the rule. The navigation accuracy of the airplane is one factor in this buffer. Reference 7 indicates that the present estimated delivery accuracy (20 seconds - one sigma, Reference 10) can be improved to about 3 seconds using CDTI equipment.

To quantify this potential benefit the Boeing runway operations rate model used in the preceding analysis has been exercised with the parameters of Table 6-5. Results are shown in Figure 6-2 and Table 6-6. The gains attributable to CDTI from improved delivery accuracy with a 3 mile separation standard are 10 arrivals/hour over present procedures and 5, 3, and 1 arrivals per hour in the Basic M & S, Advanced M & S and Closed-Loop-Time-Control environments respectively. Table 6-7 shows runway operation rates for an equal arrival and departure mix.

No improvement in departure operations are assumed. These results have been applied to the 24 airports in Table 6-2 that were identified as having capacity problems by the year 2005 (Group A and C airports). This list includes airports that account for over half of today's air carrier operations and 90% of the delay. Gains are applicable for all weather conditions

TABLE 6-5 RUNWAY OPERATIONS RATE MODEL INPUTS

PARAMETER	VALUE
OUTER MARKER DELIVERY ACCURACY	0 TO 20 SECONDS
DISTANCE SEPARATION	2 OR 3 N. MI.
FINAL APPROACH LENGTH	5 MILES
REFERENCE VELOCITY (MEAN)	125 KNOTS
REFERENCE VELOCITY (S.D.)	7 KNOTS
TOUCHDOWN DISTANCE (MEAN)	1514 FEET (FROM THRESHOLD)
TOUCHDOWN DISTANCE (S.D.)	593 FEET (FROM THRESHOLD)
SPOILERS UP TIME (MEAN)	5.7 SECONDS
SPOILERS UP TIME (S.D.)	2.4 SECONDS
BRAKES ON TIME (MEAN)	2.4 SECONDS
BRAKES ON TIME (S.D.)	0.3 SECONDS
BRAKING DECELERATION (MEAN)	6.0 FEET/SEC ²
BRAKING DECELERATION (S.D.)	0.7 FEET/SEC ²
GROUND ROLL DECELERATION	2.89 FEET/SEC ²

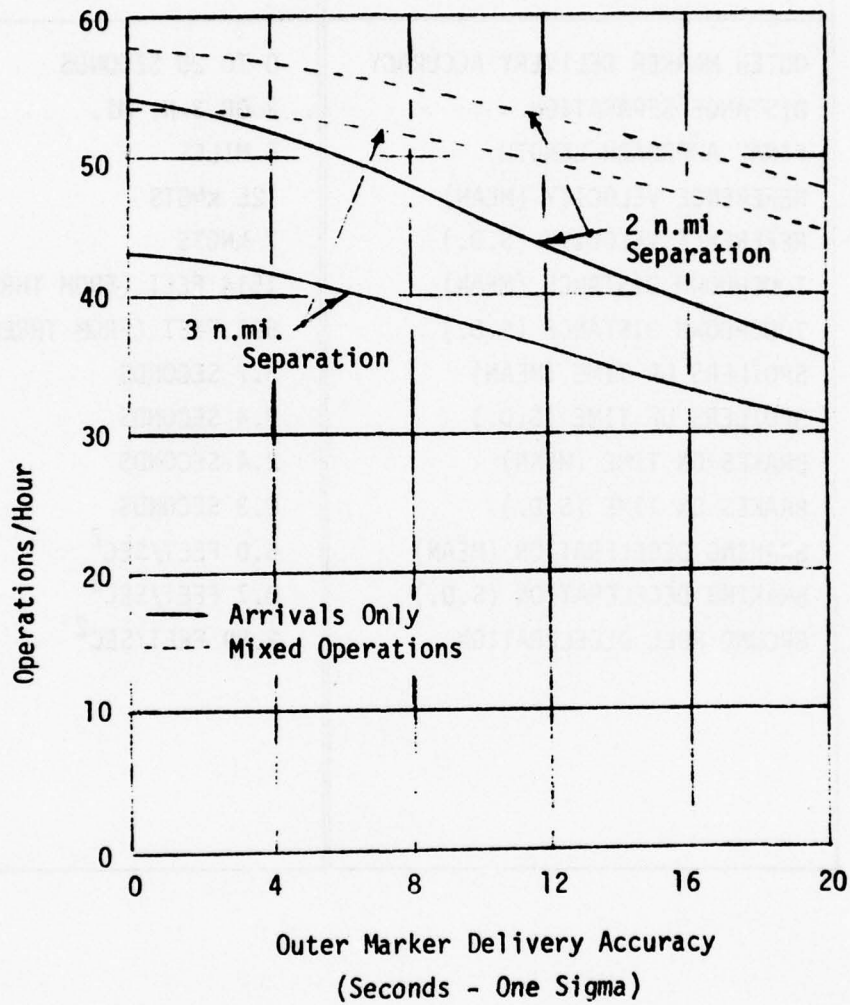


FIGURE 6-2 DELIVERY ACCURACY-CAPACITY SENSITIVITY

TABLE 6-6 LONGITUDINAL SPACING BENEFITS - ARRIVALS ONLY

ATC SYSTEM LEVEL	ASSUMED OUTER MARKER DELIVERY ACCURACY (SEC-ONE SIGMA)	SINGLE RUNWAY - ARRIVALS/HOUR	
		3 MILE SEPARATION	2 MILE SEPARATION
PRESENT	20 *	32	37
BASIC M & S	11 *	37	44
ADVANCED M & S	8 *	39	48
CLOSED-LOOP TIME CONTROL	5 *	41	51
CDTI	3 **	42	53

* REFERENCE 13

** REFERENCE 7

TABLE 6-7 LONGITUDINAL SPACING BENEFITS MIXED OPERATIONS

ATC SYSTEM LEVEL	SINGLE RUNWAY - OPERATIONS/HOUR	
	3 MILE SEPARATION	2 MILE SEPARATION
PRESENT	44	47
BASIC M & S	50	53
ADVANCED M & S	51	55
CLOSED-LOOP TIME CONTROL	52	56
CDTI	53	57

TABLE 6-6 LONGITUDINAL SPACING BENEFITS - ARRIVALS ONLY

ATC SYSTEM LEVEL	ASSUMED OUTER MARKER DELIVERY ACCURACY (SEC-ONE SIGMA)	SINGLE RUNWAY - ARRIVALS/HOUR	
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	3 MILE SEPARATION	2 MILE SEPARATION
PRESENT	44	47
BASIC M & S	50	53
ADVANCED M & S	51	55
CLOSED-LOOP TIME CONTROL	52	56
CDTI	53	57

(a 17 hour airport day is assumed). For the 24 airports examined, a determination of the most prevalent runway use is made. This configuration is used to determine the potential gain in operations capability per hour (from Tables 6-6 and 6-7 and the applicable runway environment). The annual capacity gain is estimated at 17 hours x 365 days x this hourly gain.

The increase in capacity thus obtained is then used to either reduce delay (at those airports not yet demand limited), increase operations (at demand limited airports), or both (at airports where the increased capacity allows). The results of this procedure are given as a function of year in Table 6-8 for the three mile separation case.

TABLE 6-8 ARRIVAL IN TRAIL SPACING CONTROL
CAPACITY RESULTS - (3 MILE SPACING)

ATC SYSTEM LEVEL *	NUMBER OF OPERATIONS(000)				YEARLY DELAY (MINUTES - 000)				DELAY PER OPERATION (MINUTES)			
	80	85	90	95	80	85	90	95	80	85	90	95
PRESENT	5433	5662	5709	5741	7297	8281	8441	8563	1.34	1.47	1.48	1.49
BASIC M & S	5715	6115	6565	6760	5449	6664	8733	9611	0.95	1.09	1.33	1.42
ADVANCED M & S	5768	6200	6726	6998	4850	6067	8464	9602	0.84	0.98	1.26	1.37
CLOSED-LOOP TIME CONTROL	5782	6270	6828	7217	4233	5571	7710	9612	0.73	0.89	1.13	1.33
CDTI	5782	6307	6877	7327	3766	5291	7271	9496	0.65	0.84	1.06	1.30

* SEE TABLE 6-6 FOR ASSUMPTIONS

6.4 Longitudinal Separation of Arrivals Monitor

Use of CDTI could also be a factor in reducing the along-track separation requirements assuming that wake turbulence constraints can be alleviated. The present spacing rules are a function of the basic surveillance system accuracy and update rate and various other factors such as controller response time, airplane precision in following ATC instructions, communication delay, etc. The CDTI system promises improvement in these factors so that combined with ATC improvements, a 2 n.mi. spacing may be considered safe (Reference 7).

Tables 6-6 and 6-7 give the operations rates as a function of outer marker delivery accuracy for this two mile spacing. The capacity gains for this environment were calculated and translated into delay as shown in Table 6-9.

For comparative purposes the data for both the three mile and two mile separation cases has been presented in histogram form. In Figure 6-3 the cumulative 20 year (1980 - 1999) totals are shown.

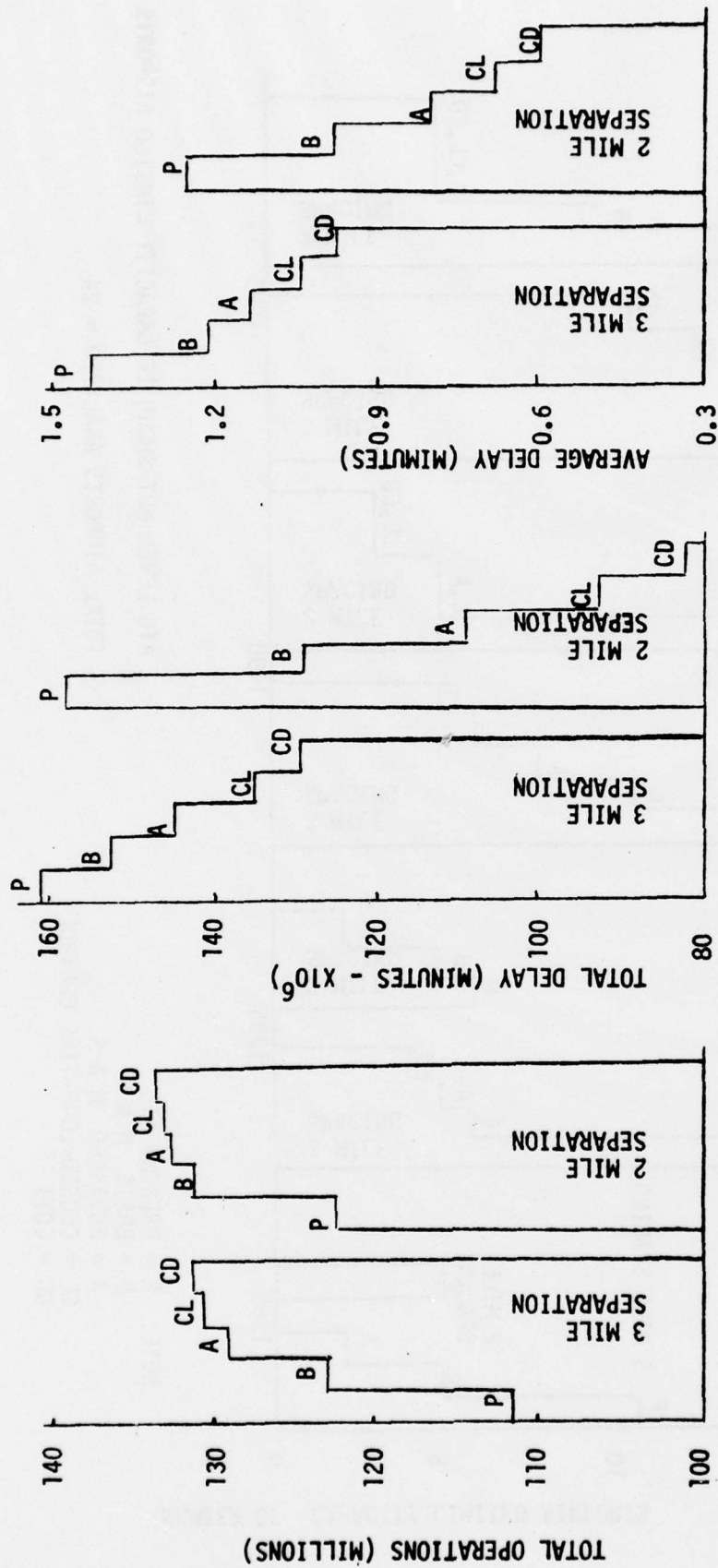
Figure 6-4 shows the number of capacity limited airports for the various control environments. Of the 24 airports determined to be heavily loaded by 2005, 23 are limited under present rules by 1995. A two mile separation rule and the CDTI delivery accuracy could reduce this to only 5 airports.

The calculations of benefits obtained from these improvements depends mostly upon the assumed baseline over which the gain is obtained and the time period over which the gain is calculated. The data presented permits any comparison desired. Estimates for the full 20 year time period may be made using the histograms of Figures 6-3 and 6-4.

TABLE 6-9 LONGITUDINAL SPACING OF ARRIVALS MONITOR
CAPACITY RESULTS (2 MILE SPACING)

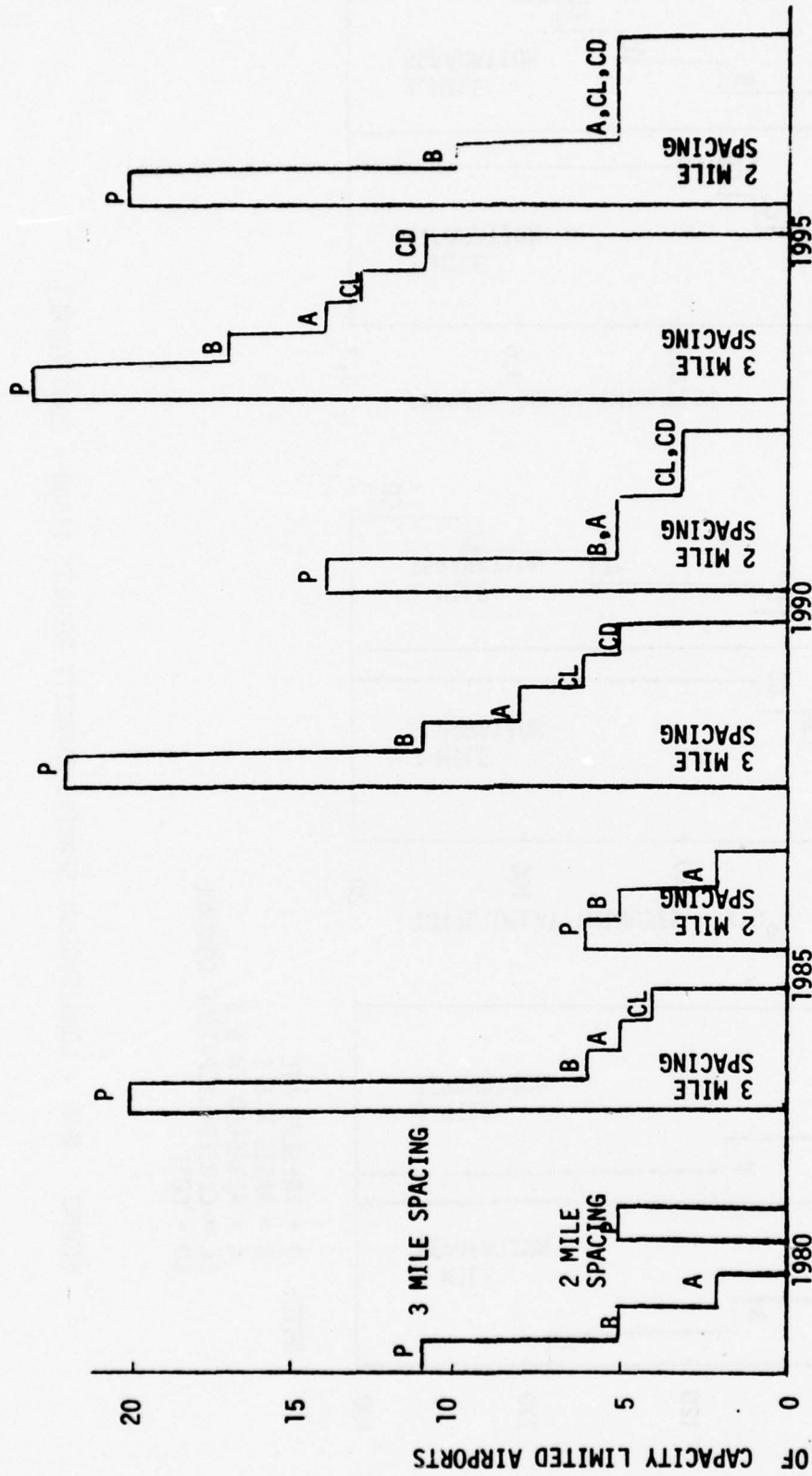
ATC SYSTEM LEVEL *	NUMBER OF OPERATIONS(000)				YEARLY DELAY (MINUTES - 000)				DELAY PER OPERATION (MINUTES)			
	80	85	90	95	80	85	90	95	80	85	90	95
PRESENT	5697	6097	6470	6614	5787	7146	9046	9734	1.02	1.17	1.40	1.47
BASIC M & S	5782	6324	6931	7424	3694	5345	7426	9394	0.56	0.85	1.07	1.27
ADVANCED M & S	5782	6387	7071	7716	2717	4210	6066	8659	0.47	0.66	0.86	1.12
CLOSED-LOOP TIME CONTROL	5782	6390	7160	7816	2179	3446	5426	7411	0.38	0.54	0.76	0.95
CDTI	5782	6390	7196	7883	1870	2927	4892	6765	0.32	0.46	0.68	0.86

* SEE TABLE 6-6 FOR ASSUMPTIONS



NOTE: P = PRESENT ATC
 B = BASIC M & S
 A = ADVANCED M & S
 CL = CLOSED-LOOP-TIME CONTROL
 CD = CDTI

FIGURE 6-3 - LONGITUDINAL SPACING CAPACITY RESULTS (1980 - 2000 TOTAL)



NOTE: P = PRESENT ATC

B = BASIC M & S

A = ADVANCED M & S

CL = CLOSED-LOOP-TIME CONTROL

CD = CDTI

- ATC LEVEL NOT SHOWN IF CAPACITY LIMITED AIRPORTS = 0

- TOTAL AIRPORTS ANALYZED = 24

FIGURE 6-4 - LONGITUDINAL SPACING RESULTS - CAPACITY LIMITED AIRPORTS

Present plans for implementation of the basic M & S, advanced M & S and closed-loop-time-control systems are not firm. However, assuming that the CUTI is installed and operating at the 24 airports analyzed by 1980, the basic M & S is operational by 1985, advanced M & S in 1990, and a closed-loop-time-control system by 1995, benefits obtained from the CDTI increase in arrival accuracy for a 3 mile separation standard and for a 2 mile standard are shown in Table 1.2-2 (Summary Section). The two mile standard requires alleviation of wake turbulence constraints and also improvements in other capacity related ATC and airport factors. Summarized gains from the parallel approach analysis are also shown for comparison. If the assumed baseline for comparison is taken to be the present 3 mile separation standard (this amounts to attributing all gain to the CDTI alone) the data in Table 1.2-1 (Summary Section) can be applied.

6.5 Other CDTI Benefit Considerations

The CDTI has other benefits attributed that have not been quantified in this study (Table 6-10). For example, no departure capacity analysis was performed. Other capacity gains may come from improved surface control, communications, and visibility using CDTI.

Another area not quantified is that of safety improvements from CDTI. The classical (a priori) method of assigning probabilities to events involves enumerating all possible outcomes and determining the number of these outcomes that represent the event of which the probability is to be estimated. In ATC safety analysis, the typical event to be determined is a collision as a function of the total flying hours. This probability is related to airline safety statistics and is considered "safe" if the risk is much less than the risk currently accepted in flying. There are many problems in this method. One arises in determining the number of collisions expected. Obviously, if a cause of collision can be determined, the situation is changed so that this cause is eliminated. This implies that collisions are caused by events that are unexpected and can't be predicted ("blunders"). Therefore, the confidence level associated with a collision estimate must be low. Another problem arises from the large number of events involved in ATC situations. The task of enumerating them all is impossible and methods of estimation must simplify the enumeration, again lowering confidence. Finally, "acceptable" collision risks usually involve numbers in the range of 10^{-7} and smaller. Essentially all of these numbers are zero, although ratios may be very large. All of these considerations tend to make safety analyses valuable only in a relative sense and then only when comparing small single parameter changes in otherwise identical systems. In the case of this study, the usefulness of quantifying safety in comparing concepts of such large differences is doubtful. A qualitative approach appears to be of more use.

In this regard, improvements, in IFR safety for the CDTI derive from providing a cross-check on the ground-based separation assurance system. This assumption results from the upgraded third generation system environment that has the ground-based surveillance system as the primary separation

TABLE 6-10 POTENTIAL BENEFIT AREAS

CANDIDATE CDTI ROLES		POTENTIAL BENEFIT AREA			
		SAFETY	AIRSIDE CAPACITY	ATC CAPACITY AND COST	FLIGHT EFFICIENCY
TRAFFIC MONITOR	General TMA Operations	(X)		X	
	Longitudinal Spacing of Arrivals	X	(X)	X	
	Independent Parallel Approaches		(X)		
	Airport Surface Taxiing	(X)	X		
	En Route	X	(X)		
	Overocean	X	(X)		X
	Runway Occupancy Monitor	(X)	X		
AIRBORNE COLLISION AVOIDANCE	General TMA Operations	X		X	
	Longitudinal Spacing of Arrivals	X	(X)	X	
	Independent Parallel Approaches	X	(X)		
	Airport Surface Taxiing	(X)	X		
	En Route	X	(X)	X	
	Overocean	X	(X)	X	X
AIR TRAFFIC CONTROL	Arrival Merging			(X)	X
	Arrival In-Trail Spacing Control		(X)	X	X
	Departure Separation		(X)	X	
	En Route Passing and Crossing		X	(X)	X
	En Route Spacing Control (Lateral and Longitudinal)		(X)	X	
	Severe Weather Avoidance Separation	(X)		X	
	Separation While Taxiing	(X)	X	X	

(X) Major Benefit

assurance device. When the two systems use the same traffic information source, some of the advantages that accrue from dissimilar redundancy can not be obtained.

One factor that could possibly degrade safety would be any tendency to use the CDTI as the primary navigation device in the terminal area. This leads to dependent navigation and surveillance (airborne) with the communication link required for both. A failure of the data link would require a reversion to a backup navigation mode with some added safety risk.

The preceding discussion applies mostly to the IFR controlled situation. In an uncontrolled VFR environment, the CDTI has the potential of reducing collision risk to levels close to those obtained in air carrier operations. The full effect may not be obtained due to the potential for a CDTI to add to flying accidents by failure, misinterpretation of display, workload increases, lack of knowledge about intent of other airplanes, etc.

7.0 TEST SCOPE AND OBJECTIVES

The basic premise for this study was that the use of cockpit displayed traffic information has been extensively studied and simulated, and it is time to flight test the concept. The study plan was to formulate a unified system concept and identify the scope and objectives for a test program to determine the performance of a CDTI system in a realistic flight and traffic environment. The performance achieved can then be used to establish the feasibility of the proposed operations and substantiate the potential benefits.

7.1 Test Scope

The required testing consists of simulations and flight tests. The program is based on four simulation/test configurations.

- 1) A CDTI airplane flight simulator;
- 2) A CDTI flight test airplane operating in a limited simulated traffic environment;
- 3) A real-time terminal area ATC system simulator;
- 4) A CDTI flight test airplane operating in a busy terminal area.

Figure 7.1-1 shows the relationships in the test program using these configurations. The flight simulator tests will provide an initial performance assessment and the design of the flight test CDTI equipment. The flight test program will check the results of the flight simulator tests in a real flight environment. The ATC simulation and busy terminal area flight tests require extensive investments in the test configuration. Therefore, at this point the program would be reassessed as to potential use in the ATC system. If this reassessment is positive, the ATC simulation and busy terminal area flight test programs would be considered.

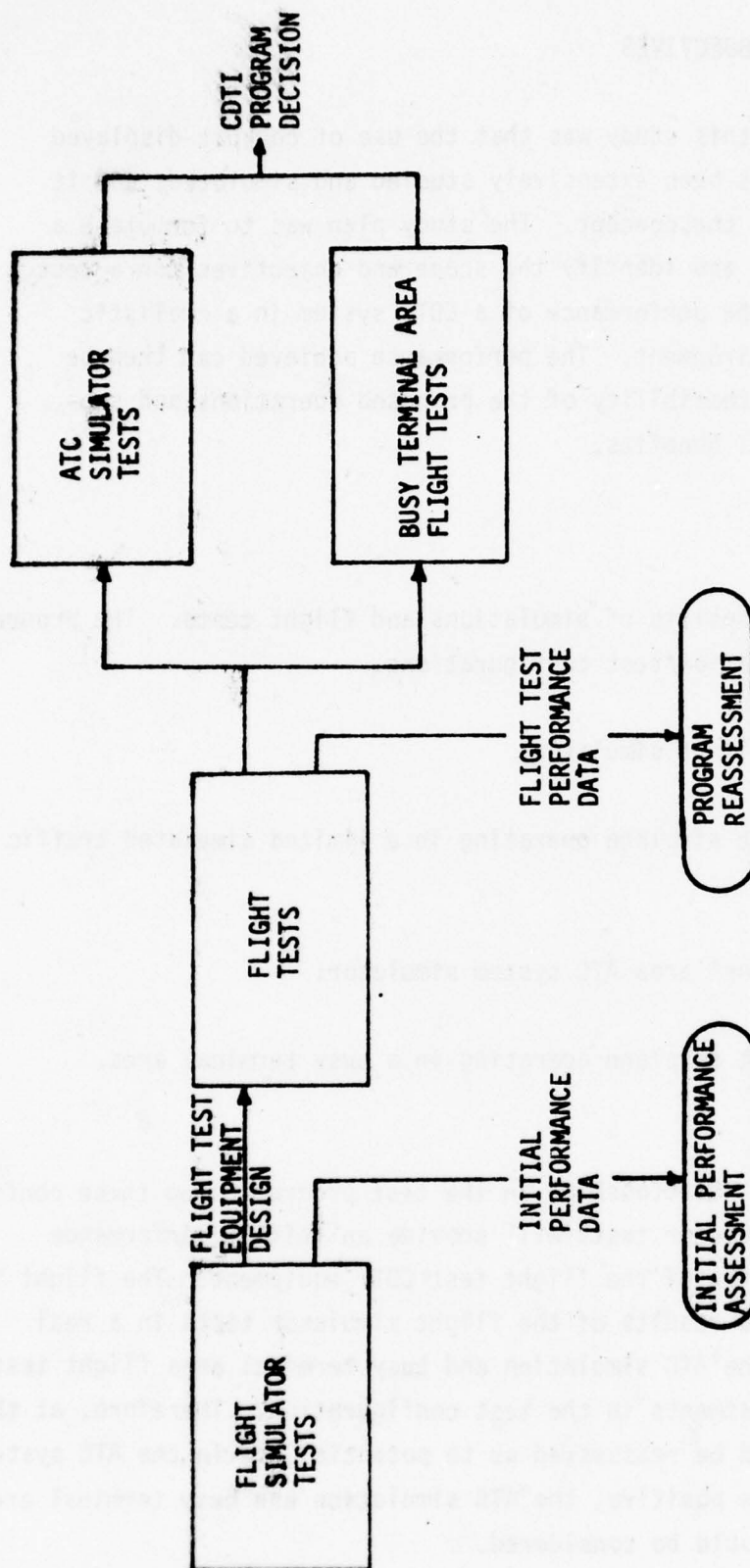


FIGURE 7.1-1 CDTI TEST SCOPE

There exist two significant constraints which limit the scope of possible testing and must be recognized in designing the test program.

1) Inadequate Statistical Base

The monitor roles ideally should be tested for performance in detecting a rare event (loss of separation). However, no firm conclusions can be drawn from a real-time simulation or flight test that simulates an event which may occur only once in thousands of hours of flight. If the event is simulated, the subject pilot will be expecting it, and any ability to detect and react does not represent the real world. Similarly the subject pilot may react to a situation which he erroneously judges to be a conflict; probably reflecting lack of experience in using the CDTI.

2) Potentially Expensive Test Configurations

A real-time ATC simulation to investigate the ATC aspects of CDTI probably requires a NAFEC level of capability involving simulating a complete busy terminal area IFR room at least. Similarly, operation in a busy terminal area will require modifying the ARTS III computer program to supply the target data and implementing a data link. It may not be possible to use safely the ARTS III computer program for test purposes while it is also controlling traffic. In any case, both of these test configurations will be complex and expensive.

7.2 Test Objectives

The general objectives of the simulation and flight testing are to:

- 1) Develop the design of the airborne CDTI elements and operational procedures to a point at which they reasonably represent the necessary capabilities of an operational system;
- 2) Determine which roles are operationally feasible considering both flying and ATC operations; and
- 3) Measure the achievable performance as a basis for refining the benefits estimates.

7.2.1 Flight Simulator Tests

The test configuration consists of:

- 1) A flight simulator of a jet transport type aircraft (e.g., the NASA 515) equipped with an EHSI including the CDTI capabilities;
- 2) A simulated ATC control facility with voice communications between the ATC controller and simulator pilot;
- 3) Target airplane simulators including at least one piloted simulator;
- 4) A system simulating the DABS, ARTS III and DABS data link operation in obtaining and transmitting traffic data to the CDTI display.

The scenario used for the tests should represent busy terminal area operations. Traffic situations and flight profiles for operations in several terminal areas with different airspace (e.g., Atlanta, Chicago O'Hare, Denver, and Los Angeles) should be used. Test scenario considerations are discussed under the individual role concepts in Section 4.0.

7.2.1.1 Monitor Roles

The test objectives are as follows:

General Terminal Area Operations Monitor

- 1) Determine target symbols and data block content and location which provide best available presentation considering other EHSI displayed data.
- 2) Evaluate target update and refresh rate requirements.
- 3) Determine need for target track or heading information.
- 4) Determine "pertinent traffic" to be displayed based on pilot workload and interest.
- 5) Evaluate overall ability of pilot to keep up with traffic situation (e.g., stop action quizzes).
- 6) Assess false alarm rate.
- 7) Assess possibility of successfully detecting blunder.
- 8) Assess possibility of negatively affecting basic flying (i.e., mistakes due to CDTI distraction).

Longitudinal Spacing of Arrivals

- 1) Develop a display mark which best indicates the minimum longitudinal separation standard from the airplane ahead.
- 2) Evaluate the pilots performance while flying this role as to answering these questions:
 - a) Is separation monitoring a significant workload factor?
 - b) Does separation monitoring reduce the basic flying performance?
 - c) Will the pilot maintain attention and detect loss of separation?
 - d) Will the pilot react to the separation data and produce undesirable effects such as slowing down when separation is intended to decrease?

Independent Parallel Approaches

- 1) Develop the CDTI presentation showing both final approach paths, runways and a mark indicating excessive lateral excursion of parallel traffic.
- 2) Determine how many targets are useful, in addition to the one that is on the parallel track and within the longitudinal separation standard.
- 3) Evaluate the pilots performance while flying this role to determine:
 - a) Will the monitoring workload detract from flying performance (less accurate approaches, bad landings, etc.)?
 - b) Will the pilot detect a rare-event loss of lateral separation?
 - c) Will the pilot react unnecessarily due to acceptable lateral excursions of parallel traffic?

Runway Occupancy Monitor

- 1) Determine the target symbols and presentation format which provides best available presentation considering EHSI displayed data.
- 2) Determine the extent of target information required to be shown for parallel or crossing active runways.
- 3) Evaluate target update and/or refresh requirements.
- 4) Determine the "pertinent traffic" to be displayed based on pilot workload and interest.
- 5) Assess false alarm rate.
- 6) Assess possibility of successfully detecting rare event blunders under realistic workload environment.
- 7) Assess possibility of negatively affecting basic flying (i.e., mistakes due to CDTI distraction or EHSI clutter),
- 8) Evaluate overall ability of pilot to interpret properly the runway occupancy traffic situation.

7.2.1.2 ATC Roles

The test objectives are as follows.

Arrival Merging

- 1) Determine the information the CDTI pilot needs on the EHSI and the best way to present it to accomplish a merging.
- 2) Measure the precision with which a pilot can merge into a stream or behind another aircraft at a specified longitudinal spacing and geographical position.
- 3) Examine various traffic situations and determine those in which CDTI merging may be satisfactorily performed.
- 4) Investigate the human factors aspects including:
 - a) Workload intensity and effect on successfully completing the maneuver;
 - b) Effects on basic flying and possibility of deterioration in performance; and
 - c) Unplanned pilot actions and effects on traffic situation.

Arrival In-Trail Spacing Control

- 1) Determine the information needed to satisfactorily accomplish this operation.
- 2) Develop the best method of displaying this information.
- 3) Determine which portions or types of arrival flight profiles are amenable to CDTI in-trail spacing control, based on the pilot successfully maintaining spacing and the CDTI airplane staying within its acceptable flight envelope.
- 4) Determine the spacing accuracy that can be expected.
- 5) Investigate the human factor aspects including:
 - a) Workload intensity and effect on successfully completing the maneuver,
 - b) Effects on basic flying and possibility of deterioration in performance, and
 - c) Unplanned pilot actions and effects on traffic situation.

Departure Separation

- 1) Determine the guidance displacement and rate information needed to best maintain departure separation in the longitudinal, vertical and lateral directions.
- 2) Determine the best method of presenting this information on the EHSI.
- 3) Determine which portions and types of departure profiles are feasible

for CDTI separation, based on the pilot successfully maintaining spacing and the CDTI airplane staying within its acceptable flight envelope.

- 4) Investigate the human factor aspects including:
 - a) Workload intensity and effect on successfully completing the maneuver,
 - b) Effects on basic flying and possibility of deterioration in performance, and
 - c) Unplanned pilot actions and effects on traffic situation.

En Route Passing and Crossing

- 1) Determine the information (e.g., lateral displacement, target speed, target heading, etc.) needed to accomplish satisfactorily the passing maneuver, and the means of displaying this information.
- 2) Determine the information needed to satisfactorily accomplish the crossing maneuver and the means of displaying this information.
- 3) Verify that the CDTI pilot can satisfactorily maintain separation while accomplishing the passing maneuver.
- 4) Investigate the human factor aspects including:
 - a) Workload intensity and its effect on successfully completing the maneuver,
 - b) Effects on basic flying and possibility of deterioration in performance, and

- c) Unplanned pilot actions and effects on the traffic situation (e.g., misinterpreted dynamic situation resulting in an incorrect maneuver and loss of safe separation).

Severe Weather Avoidance Separation

- 1) Determine the information needed to select and fly a path safely separated from other traffic.
- 2) Determine the best method of displaying the needed information on the EHSI.
- 3) Verify that the pilot can satisfactorily maintain separation while avoiding severe weather and maintaining aircraft flight within a safe portion of the flight envelope.
- 4) Investigate the human factor aspects including:
 - a) Workload intensity and effect on successfully completing the maneuver,
 - b) Effects on basic flying and possibility of deterioration in performance, and
 - c) Unplanned pilot actions and effects on the traffic situation.

7.2.2 Flight Tests

The test configuration consists of:

- 1) A jet transport type aircraft equipped with an EHSI including the CDTI equipment as defined from the flight simulator test results.
- 2) A simulated ATC control facility with voice communications between the ATC controller and CDTI airplane pilot.
- 3) Target airplane simulators including at least one piloted simulator.
- 4) A system simulating the DABS and ARTS III operation in obtaining traffic data.
- 5) A data link for transmitting traffic data to the airplane in a mode simulating DABS data link operation.
- 6) An instrumentation system for measuring the flight test airplane track for correlation with simulated traffic tracks.

Basically, the flight tests are repeats of the flight simulator tests and the objectives are the same. The purpose of flight testing being to add a real flying environment to the operation.

7.2.3 ATC Simulation Tests

The test configuration consists of:

- 1) A simulation of a busy terminal area IFR room complete with:**
 - a) All control positions and operating personnel;**
 - b) Piloted aircraft simulators for all traffic including a variable percent which are CDTI equipped, and**
 - c) Simulation of DABS, ARTS III and DABS data link.**

The objectives of the tests are to assess the ATC aspects of CDTI operation including:

- 1) Control workload;**
- 2) Procedures;**
- 3) Airspace Usage; and**
- 4) Operational suitability (are the CDTI operations safe and reliable?).**

7.2.4 Busy Terminal Area Flight Test

The test configuration consists of:

- 1) A busy terminal area ARTS III IFR room;
- 2) An ARTS III computer program modified to output traffic data addressed to the CDTI airplane;
- 3) A data link for transmitting the traffic data to the airplane in a mode simulating the DABS data link;
- 4) A CDTI flight test airplane; and
- 5) Controllers trained in CDTI procedures.

The objectives of these tests are to assess CDTI pilot performance in a live traffic situation, test CDTI procedures, and generally gain experience with CDTI operations under actual conditions.

APPENDIX

LIST OF ABBREVIATIONS AND ACRONYMS

AEROSAT	-	Aeronautical Oceanic Satellites
ARTCC	-	Air Route Traffic Control Center
ARTS	-	Automated Radar Terminal System
ASTC	-	Airport Surface Traffic Control
ATA	-	Air Transport Association
ATC	-	Air Traffic Control
ATCAC	-	Air Traffic Control Advisory Committee
ATCRBS	-	Air Traffic Control Radar Beacon System
ATSD	-	Airborne Traffic Situation Display
B-CAS	-	Beacon - Collision Avoidance System
CAS	-	Collision Avoidance System
CDTI	-	Cockpit Displayed Traffic Information
CRT	-	Cathode Ray Tube
DABS	-	Discrete Address Beacon System
DME	-	Distance Measuring Equipment
EHSI	-	Electronic Horizontal Situation Indicator
EPR	-	Engine Pressure Ratio
FAA	-	Federal Aviation Administration
5D	-	Five-Dimensional (x, y, z, t, v)
4D	-	Four-Dimensional (x, y, z, t)
FSS	-	Flight Service Station
HF	-	High Frequency
IAF	-	Initial Approach Fix
IFR	-	Instrument Flight Rules
ILS	-	Instrument Landing System
IMC	-	Instrument Meteorological Conditions
IPC	-	Intermittent Positive Control
KCAS	-	Knots Calibrated Air Speed
KIAS	-	Knots Indicated Air Speed
MSAW	-	Minimum Safe Altitude Warning

APPENDIX

List of Abbreviations and Acronyms (continued)

M&S	-	Metering and Spacing
MLS	-	Microwave Landing System
NAFEC	-	National Aviation Facilities Experimental Center
NAS	-	National Aviation System; also National Airspace System
NASA-515	-	National Aeronautics and Space Administration - 515 (B-737 Airplane)
PWI	-	Proximity Warning Indicator; also Pilot Warning Instrument
RNAV	-	Area Navigation
TAGS	-	Tower Automated Ground Surveillance
TCA	-	Terminal Control Area
3D	-	Three-Dimensional (x, y, z)
TMA	-	Terminal Area
TRACON	-	Terminal Radar Approach Control
2D	-	Two-Dimensional (x, y)
UG3RD	-	Upgraded Third Generation
VFR	-	Visual Flight Rules
VHF	-	Very High Frequency
VMC	-	Visual Meteorological Conditions
VOR	-	Very High Frequency Omnidirectional Range
WVAS	-	Wake Vortex Avoidance System

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